010403

MANUALS OF ELEMENTARY SCIENCE.

CHEMISTRY.

BY

ALBERT J. BERNAYS, PH.D., F.C.S.,

Professor of Chemistry and of Practical Chemistry at St. Thomas's Hospital, &c.

PUBLISHED UNDER THE DIRECTION OF
THE COMMITTEE OF GENERAL LITERATURE AND EDUCATION,
APPOINTED BY THE SOCIETY FOR PROMOTING
CHRISTIAN KNOWLEDGE.

LONDON:
SOCIETY FOR PROMOTING CHRISTIAN KNOWLEDGE;
SOLD AT THE DEPOSITORIES:
77, GREAT QUEEN STREET, LINCOLN'S INN FIELDS
4, ROYAL EXCHANGE; 48, PICCADILLY;
AND BY ALL BOOKSELLERS.

NEW YORK: POTT, YOUNG & CO.

1874.

[*All Rights reserved.*]

LONDON:
Printed by Jas. Truscott and Son,
Suffolk Lane, City.

CONTENTS.

PAGE

CHAPTER I.—On some of the Physical and Chemical Properties of Water—Water not an Element, but a Compound of two Elements ....7—16

CHAPTER II.—The Atmosphere, in its relations to Animal and Vegetable Life—The Air not an Element, but a Mixture of two Elements, Oxygen and Nitrogen, with small quantities of certain Compounds ....16—28

CHAPTER III.—Traces of Impurities in the Air—On the Diffusion of Gases—The Weight of the Air—The Barometer—The Nature of Clouds—Clouds, a kind of Barometer...29—40

CHAPTER IV.—The Nature of Burning—The Chemistry of Coal and of a Coal-Fire—Difference between Coal and Coke—The Nature of Gases in Coal-Gas ....40—49

CHAPTER V.—The Nature of Flame—Bodies increase in Weight when they are burnt—The Blowpipe Flame—The Davy-Lamp—Different kinds of Gas-Jets—Candles. Use of Wicks—Stearin and Palmitin—Wax—Carbonic Acid and Water are formed in the Burning of Candles, and thrown into the Air....49—61

CHAPTER VI.—On the Chemistry of the Four Elements, Hydrogen, Oxygen, Carbon, and Nitrogen, and of their Compounds ....61—71

CHAPTER VII.—The Chemistry of the Elements Sulphur and Phosphorus, with a few words about Lucifer-Matches ...72—78

CHAPTER VIII.—The Elements Chlorine, Bromine, Iodine, and Fluorine, considered in relation to one another and to Hydrogen ....78—84

PAGE

CHAPTER IX.—The Elements Silicon, Boron, and Arsenicum, and their Compounds, with an Explanation of Etching Glass .... 84—91

CHAPTER X.—Introduction to the Metals—Continuation of Tables of the Elements—General Properties—Meaning of an Ore—The Principles upon which the getting of the Metals from their Ores depends .... 91—101

CHAPTER XI.—On certain Carbonates and Silicates, together with a Short Description of Glass, China, and Earthenware .... 102—113

CHAPTER XII.—Other Metallic Salts .... 113—119

CHAPTER XIII.—Illustrations of Metallic Oxides and Hydrates, with a Short Description of the Salts called Soaps...... 119—123

CHAPTER XIV.—Concluding Remarks........ 123—126

ELEMENTARY CHEMISTRY.

INTRODUCTORY REMARKS.

Chemistry is that branch of science, or knowledge, which is concerned with the nature and properties of matter. A comprehensive subject, including, as it does, everything in earth, and air, and sea;—everything indeed which occupies space and is possessed of weight.

In the common language of science the terms "physical" and "chemical" often occur, and therefore require some explanation.

The **physical** properties of a body are those which refer to its "natural" condition, as the Greek word signifies from which physical is derived. Thus all bodies are either solid, liquid, or gaseous. They may vary in hardness, in crystalline form, in colour, transparency, and in the different effects of heat and electricity upon them. These are physical properties, and we observe that they do not notice the composition of bodies. A piece of pure gold may be so strongly heated that it melts; it may be divided into parts so small as almost to surpass belief, yet each part would consist only of gold. But, if we heat a piece of paper, it browns or blackens before it burns; if, when burning, we hold a dry tumbler over it, the latter will be covered with dew or water. Charcoal and water may therefore be obtained, and thus a difference is established between the composition of the gold and paper, which it is the province of Chemistry to study.

The term **chemical** is given to the changes which permanently affect the character of bodies.

All bodies are either **simple** or **compound.** In compounds, two or more simple bodies are so united together according to fixed rules, that their individual characters are, for the time, lost.

A simple body is called an element. A simple body or element cannot be turned into any other form of matter. As in the case of gold, which is an element, no treatment can bring from it anything but gold.

The Ancients looked upon air, earth, fire, and water as elements. But, as it is easy to obtain simpler forms of matter out of air, earth, and water, modern chemists do not look upon them as elements. As for fire, it is merely the result of the action of high temperatures on certain bodies.

Many of the elements are well known. Gold, silver, copper, lead, zinc, tin, iron, and mercury are household words; these are all elements. But many elements are so very rare as to be almost unknown. Others again, like oxygen, hydrogen, and nitrogen, are less known, because they are unseen and exist only as gases. Only two of the elements are met with naturally in the liquid state, bromine and mercury.

Although Physics is a study quite apart from Chemistry, there is no possibility of studying Chemistry without reference to Physics.

Chemistry relates essentially to the actions of bodies upon one another, and to the lasting changes which they either produce or experience.

But, as the introduction to a book is often passed over, further explanations had better be postponed for the present.

[The portions of the text, which are included within brackets, may be omitted by beginners.]

CHAPTER I.

ON SOME OF THE PHYSICAL AND CHEMICAL PROPERTIES OF WATER—WATER NOT AN ELEMENT, BUT A COMPOUND OF TWO ELEMENTS.

1. It has been already stated that the ancients considered water to be an element or simple body; the contrary, however, may be easily proved. It is a compound of two elements, one of which is called **Oxygen,** the other **Hydrogen.** In chemical language, **water** is an **Oxide of Hydrogen.**

2. The difference between a **mixture** and a **compound** is well illustrated by water. The two elements, oxygen and hydrogen, which, when united in fixed proportions, form liquid water, exist naturally, and in the separate state, as gases. In a mixture, bodies retain their individual characters; in a compound, they are either lost or disguised.

3. Water, when pure, and in small quantity, is a colourless liquid; seen in mass, it is blue. It is without taste or smell. But water can exist in three states—as a liquid, a solid, and a vapour. At temperatures below the freezing-point we are familiar with it in the form of ice, and we all know how readily it rises in vapour.

4. The atmosphere always contains a certain amount of water in the condition of vapour, the quantity of which depends upon temperature. A very homely illustration of these two facts—the existence of watery vapour in the air and its variation with the temperature—is daily seen. If a decanter filled with cold water is brought into a warm room, its surface is immediately covered with dew. The air in contact with the decanter, being cooled down by the water, is no longer able to

contain the vapour present in it, and it therefore condenses. A still more familiar illustration of the kind is the condensation of moisture in the air breathed out from the lungs. In winter, when the outer air is much colder than the breath, the moisture is seen as a small cloud; but in summer, when the temperature of the air and that from the lungs are more nearly equal, the moisture from the breath is not visible.

5. Indeed, the effects of heat are very remarkable and worthy of attentive study. Water boils at a temperature of 100° Centigrade, and, in the form of steam so enlarges its bulk, that it occupies a space 1,696 times as great as in the liquid state.

6. At the moment of freezing, water expands so much that ice is lighter than water, and therefore floats. In the act of freezing, water is one of the most powerful agents in the formation of soil from the hardest rocks; these are broken up through the formation of ice, and by degrees rendered sufficiently small to allow of the growth of plants. During a severe winter the water contained in the pores of the soil freezes, and in expanding causes a breaking up of the hard clods. This expansion of freezing water is sometimes unpleasantly brought home to us by certain domestic inconveniences. Of these the breaking of water-jugs is the least. A far more important one is the bursting of water-pipes, for which the thaw has usually but unjustly the credit. The fracture takes place during the frost; the thaw, by turning the ice into water, only brings the mischief to light. Very slight precautions to protect the pipes from the frost will entirely prevent such accidents.

7. If a vessel filled with broken ice be placed in a warm room, the ice will gradually melt; but a thermometer placed in it will continue to show the same temperature as long as any ice remains unmelted. The heat of the room is simply employed in overcoming the solidity of the ice, and in enabling the particles to move readily.

8. Indeed, this constant temperature of melting ice

has been adopted as one of the fixed points of all thermometers. Water is said to freeze at 0°, or zero on the scale of Centigrade. All degrees of cold below zero are indicated by the minus sign placed before the figure. Thus, — 5° C. would show five degrees of cold on the Centigrade scale.

9. Again, water expands for all degrees above 4° Centigrade, and also for all degrees below 4° C. This temperature of 4° C. indicates the point at which the density of water is greatest. This singular fact has the most important consequences in nature; on it depends, in some degree, the very life of aquatic plants and animals in the temperate and colder regions of the earth; for if the contraction of water by cold continued down to its freezing-point, each river and lake would become one mass of solid ice during every frost. There would be a continual fall of cold water to the bottom and rise of warm water to the top, till the whole was frozen, and every living thing in it must die. Were ice to obey the same laws of contraction as most other bodies, it would sink in water almost beyond the reach of the sun's heat. As it is, it floats above the warmer water, and actually protects it, so that, whatever may be the temperature of the air, the deep water is never below 4° C. Accordingly, a severe winter may kill all the fish in a shallow lake; but deep lakes, such as those of North America, never can be liable to such an accident. They contain such a mass of warmer water below, that they are never even frozen over.

10. Water is a very bad **conductor** of heat. Conduction consists in each particle taking up the motion of its neighbour and passing it on. The metals are good conductors. If a metal be heated at the top, the heat is rapidly communicated to the bottom. But water may be boiled at its surface without communicating heat downwards. Although water (like air and gases generally) is not affected by conduction, its physical property of fluidity enables it to be readily heated by **convection.**

11. By *convection* we mean the passage of heat from one portion of the fluid to another by a transfer of the particles themselves. When a liquid is heated from below (fig. 1), it expands, becomes lighter, and moves upwards; a fresh portion of the fluid descends, becomes heated in its turn, and also rises. By this means a circulation of the particles is established, bringing about by degrees an uniform temperature in the whole mass of liquid. This principle is now generally applied to heating churches and other buildings. Heat applied to the surface of liquids can produce little or no movement in its particles; being expanded by heat, and thus rendered lighter, they remain upon the surface. A very simple experiment (fig. 2) will prove this. If a glass jar be filled nearly to the brim and a sensitive thermometer inserted with its bulb downwards, and just below the surface, a layer of spirit of wine may be inflamed without imparting any heat that can be recognized by the thermometer. By performing the converse of the experiment, and laying a piece of ice upon the surface, the effect is immediately shown by a fall in the thermometer. The particles of water, being cooled, become heavier, and sink rapidly downwards.

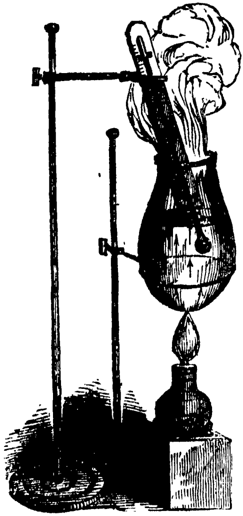

Fig. 1.

12. If the heating of water be continued, it *boils*. And here another fact meets us which is well worthy of observation. It does not matter how fierce the fire may be under the kettle, or other vessel, in which the water may be heated, the water can only boil. It is said to boil when the steam has an elastic force just sufficient

to balance and overcome the pressure of the air upon its surface. Water boils at 100° C. when the air exerts its usual pressure (par. 76); and the temperature of boiling water is so equally a fixed point, that it has been adopted in all thermometers.

13. [Water then boils at 100° C., and freezes at 0° C. Its maximum density is 4° C. One degree on the Centigrade scale, represents the 100th part of the expansion of the mercury in the thermometer.]

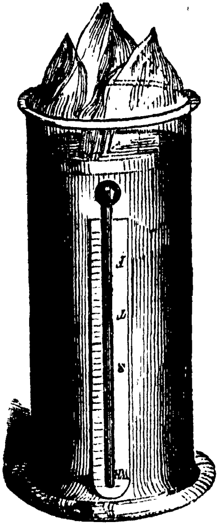

Fig. 2.

14. In the open air, the boiling-point cannot be raised, because the pressure cannot be raised. But, if water be boiled in a close vessel, as in the boiler of a steam-engine, the steam which is generated, having no escape until it can lift a certain weight, and continually increasing in quantity, gradually raises the pressure more and more to any point that may be desired; and, with the pressure, the temperature. Now, the steam which rises from the water under pressure, is called high-pressure steam.

15. Temperature and pressure are, indeed, in such close relationship, that the engineer judges of the pressure by the thermometer. The temperature of the steam is always the same as that of the water from which it rises. Advantage is frequently taken of this fact, when a steady temperature above 100° C. is required. It is turned to account in "Papin's Digester," so much used in the making of soups, and in the extraction of gelatin from bones. This consists of a strong iron saucepan, the lid of which is supplied with a safety-valve by which the pressure of steam can be regulated,

and the vessel prevented from blowing up. Some such apparatus becomes absolutely necessary to persons living on high mountains, as the temperature at which the water there boils, in the open air, is too low for common cooking purposes.

16. The formation of steam, and its subsequent condensation, is the only mode of obtaining perfectly pure water. No water, except that specially prepared for chemical purposes, is absolutely **Oxide of Hydrogen.** The purest natural water is rain ; but even that contains not only gases in solution, which it has washed from the air in its descent, but also many mechanical impurities derived from the same source. And if the rain-water has once touched the soil, its impurity is of course increased by the solution of certain salts. All these impurities may be removed by **distillation** (par. 17), the only process by which it is possible to separate a liquid from the solids which it has dissolved.

The ordinary apparatus for **distilling** is the still *a*, and worm *b*, shown in fig. 3. The worm or coiled tube which receives the steam must be passed through a large quantity of cold water. The heat being greatest in the upper coils, the upper layers of water in the worm-tub become first heated, so that if a supply of cold water *c*, is allowed to enter the bottom of the tub at *d*, the heated portions overflow at the top, and are carried away by the pipe *e* to a sink. The distilled water is collected in vessels placed for its reception.

[One pound of steam at 100° C. would, in the act of condensation in becoming simply boiling water, give up 537° C. to the water in the worm-tub. It would actually raise five pounds and one-third of a pound from the freezing to the boiling-point.]

17. Even salt water, by distillation, will yield distilled water, and such water is prepared on board ship for the general use of seamen.

18. Although distilled, or chemically pure, water is of great value to the chemist, in studying the varied properties of this important liquid, it would in its pure

state answer comparatively but few of the purposes for which it was so plentifully provided by our Maker. Its great power of dissolving solids, liquids, and gases, a power which it possesses in a higher degree than any other liquid, adapts it to its varied uses, and gives distinctive characters to rivers and seas, and indeed to water of every description. Rain-water contains varying quantities of oxygen, carbonic acid, minute quantities of carbonate of ammonium, and, during storms, of hydrogen nitrate and nitrate of ammonium. By the help of these, the rain assists in fertilizing the soil. The rain-water of towns is further rendered impure by the various exhalations, by the products of combustion of coal, by decay, and by the chemical processes there carried on.

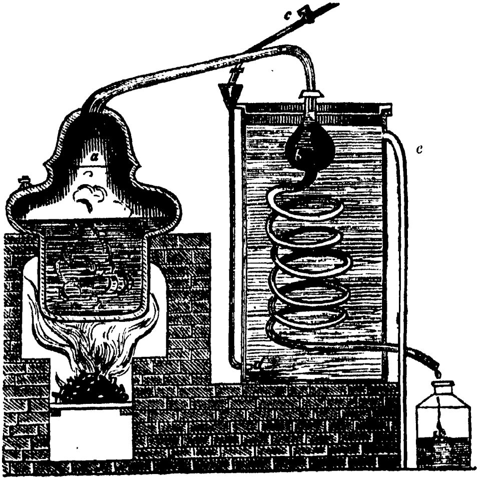

Fig. 3.

19. The washing power of rain is exerted as strongly upon solids, as upon gases. The character of the water of a river, brook, or spring, will therefore entirely depend on the nature and solubility of the soils through which its waters have passed. A limestone rock will give rise to a Calcareous water. Rich marls often contain Gypsum, and produce Selenitic waters. Some springs flow through beds of Salt, and are called Brine-springs. Others, Chalybeate, from the presence of carbonate of iron. Hepatic, or Sulphurous waters contain Sulphuretted hydrogen, and are known by the offensive smell of putrid eggs.

20. The sea is obviously the great reservoir of all matters soluble in water, while rivers, as regards the salts they contain, are but very dilute sea-water. The water of rivers is rarely as pure as spring-water, as it always contains more or less of animal and vegetable matter washed from the land; while, in England, at least, it is frequently further polluted by the drainage of towns, which renders it unfit for drinking. Rivers, and especially those whose current is strong, are, however, provided with a natural means of self-purification, in the oxydation of vegetable and animal matters through the agency of the air with which they are constantly being brought into contact; and also by the action of the various aquatic plants which give off a perpetual supply of oxygen at the very time (in summer) when it is most needed.

21. Spring-waters are generally harder than river waters, owing to the presence of a greater quantity of salts of lime and magnesia. The rocks constituting the earth's crust are, in a thousand places, rent and torn into crevices and hollows, which form natural basins for the reception of water, which accumulates in them, till, at some point or other, it finds vent as springs, very often at immense distances from the places where the water entered the ground. These underground basins and reservoirs are, of necessity, supplied with water from land at higher levels, and vent may often be given to the waters, artificially, by

boring or well-sinking, as illustrated in fig. 4. Let us suppose a basin to enclose a layer of sand *c*, between two layers, *a* and *b*, of impermeable clay. Following the natural fall of the ground, water will collect in the hollow of the basin, and will be prevented from escaping by the very nature of the clay. If a boring be now made into the stratum which contains the water, the latter will rise, fountain-like, and to a height nearly corresponding to the difference between the two levels.

22. Our modern water-works are arranged on precisely similar principles, being placed on a level above

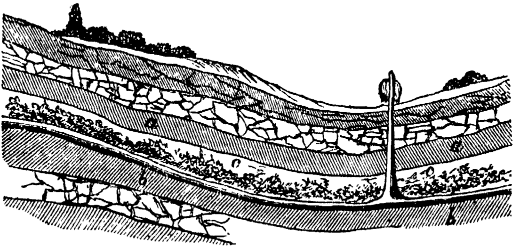

Fig. 4.

the highest houses they are destined to supply. The supply of water from an Artesian well (fig. 4) is exactly of the same character as that of the fountains at the Crystal Palace, substituting for the pipes in the latter case, the natural crevices in the strata perforated; and, for the artificial reservoirs in the water-towers, the natural hollows or basin-like formations in the earth, in the drainage area above the level of the well.

23. When water has dissolved as much of a gas, or of a solid as it can take up at a given temperature, it is said to be "saturated." If a salt dissolves in water without change of properties, and with a lowering of the temperature, simple solution is accomplished; but, if the temperature rises with a corresponding alteration

in the properties of the salt, the salt is said to be chemically dissolved. An illustration of simple solution is afforded by sugar in water; of chemical solution, by sulphate of sodium, free from its water of crystallization.

CHAPTER II.

THE ATMOSPHERE, IN ITS RELATIONS TO ANIMAL AND VEGETABLE LIFE—THE AIR NOT AN ELEMENT, BUT A MIXTURE OF TWO ELEMENTS, OXYGEN AND NITROGEN, WITH SMALL QUANTITIES OF CERTAIN COMPOUNDS.

24. The atmosphere was no long time since regarded as an element, in the same way as water. But, if we remember the present definition of an element, as a body which cannot by any known means be resolved into simpler forms, the idea cannot be entertained for a moment. It is now well known to be a mixture of several substances, in very different proportions, and of very distinctive properties.

25. What, then, is this atmosphere, without which neither life, nor that very important source of heat and light—combustion—can be supported? Of what is it made, that it can furnish so many constituents to the animal and vegetable worlds? We know it to be a transparent vapour or gas, a material substance possessed of weight, held by the attraction of gravitation to the surface of the globe, with which it revolves, and which it surrounds.

26. That the atmosphere does not consist wholly of one kind of matter is readily shown by the following experiment: A float made of cork, into which is fitted a tiny porcelain basin, and containing a piece of Phosphorus about the size of a pea, is placed in a soup-plate full of water, and over it is inverted a glass jar, open at the bottom and carefully stoppered. On re-

moving the stopper, the water will stand on a level inside and outside the jar. The phosphorus is then inflamed by means of a heated wire introduced through the neck of the bottle, and the stopper immediately replaced. The phosphorus burns brilliantly for a time, producing white vapours (of phosphoric acid), which soon dissolve in the water, which then rises in the jar (fig. 5), till it fills one-fifth of the space previously occupied by the air. By the combustion, therefore, of the phosphorus, something has been removed from the air in the jar, equal to one-fifth of its whole bulk.

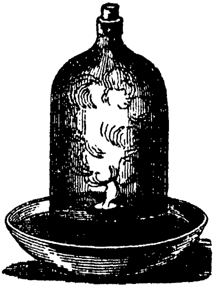
Fig. 5.

27. That it is not simply one-fifth of the volume of the air which has been removed is shown by the fact, that what remains, although clear and colourless as the air, is possessed of different properties. A lighted taper introduced into the jar is at once extinguished, proving that what is now there will not support combustion.

28. In fact, that portion of the atmosphere forming one-fifth of its bulk, that will alone support combustion, has been consumed by the burning phosphorus, and has entered into union with it. In scientific language, the Phosphorus has combined with the oxygen to form the compound, Phosphoric acid. The matter so removed is **Oxygen**; what is left behind is called **Nitrogen.**

29. Of these two invisible gases, **Oxygen** and **Nitrogen,** atmospheric air is mainly composed, in the exact proportions of 21 per cent. of Oxygen, and 79 per cent. of Nitrogen.

30. Oxygen is a colourless, tasteless, and inodorous gas, heavier than air, and very widely diffused throughout nature. It is a constituent of earth and of water, and indeed of most created things. It is an element,

and the most abundant of all the elements. All substances that burn well in air, burn with increased brilliancy in oxygen. So necessary is it to life, that oxygen used to be called "vital air." And not only to life and combustion, but also to germination. No vegetation is possible without it; indeed, a seed may be buried for many years without giving any signs of life, if placed beyond the reach of atmospheric air.

31. Nor is this all. Without oxygen there would be no decay; none of that change by which dead matter is got rid of. Heaps of fallen leaves and other refuse would collect upon the earth, were it not for this busy, active oxygen; under its magic touch they assume new and simpler forms of existence, being for the most part changed into invisible gases. In those grand processes of nature—decay, respiration, and combustion—oxygen plays the chief part. It enters into combinations with the decaying matters and the living body, and is either removed from the atmosphere, or enters it again in some new form.

32. Yet, necessary as it is, we could not live in an atmosphere of pure oxygen! If a rabbit is made to breathe pure oxygen, although it does not appear to suffer immediately, yet its respiration soon becomes very rapid, the circulation of the blood is quickened, and the animal shows signs of excitement. Symptoms of weakness appear, which are followed by insensibility, and death takes place in a few hours. This result is owing to the rapid destruction of the muscular tissues, which exceeds their powers of repair.

33. Mixed with oxygen, the atmosphere, **when dry,** contains 79 per cent. by measure of **Nitrogen.** Like oxygen, it is colourless, tasteless, and free from smell. But it does not support either respiration or combustion. Its presence in such large proportion in the atmosphere is a proof that it is not injurious to respiration, while it serves to moderate the activity of respiration as well as of combustion. From the difficulty with which it enters into combination, nitrogen is

admirably adapted for this purpose; indeed, there is no other gas which could be made to take its place.

34. Next to oxygen and nitrogen, the most important constituent of the air is **Watery vapour.** Its amount varies greatly. The quantity with us in England may be said to average 1⅔ per cent. by measure. But, as already said (par. 4), the quantity varies; the higher the temperature, the more vapour it contains. Whenever a body of air, saturated with moisture, is cooled, it must set free a portion of that moisture in some form or other, either as rain or snow, hail, mist, or dew. Now, as this process of separation is for ever going on in some part of the globe, to such an extent that the mean rain-fall for the year for the whole globe is reckoned at about 33 inches (whereas all the moisture contained in the atmosphere at any one time would cover the earth's surface to a depth of not more than five inches), it is clear that this moisture must be supplied again and again by constant evaporation. Falling to the ground in one or other of the above forms, it ministers to vegetation; while all that is not so employed either evaporates or sinks into the soil, to appear again in springs, which pour their contents into rivers, by means of which the water at last finds its way back again to the sea.

35. The simplest form of deposit is DEW. This deposit is most abundant on rough surfaces. So long as the sun shines upon soils and plants, they absorb more heat than they lose, and consequently become warmer. But, as soon as the sun sets, radiation continues from them without any sensible addition of heat; they cool rapidly, and, by lowering the temperature of the air in immediate contact with them, cause it to deposit on their surface a portion of its moisture in drops of dew.

Dew is deposited most abundantly on cloudless nights; for, when the sky is hidden by clouds, these will stop, or radiate back to the earth, a portion of the heat received from it, and prevent any great lowering of the temperature of the air near the surface of the ground. Radiation at night frequently becomes most destructive to vegetation in spring and autumn, by lowering the temperature of the air below the freezing-point of water, when the dew is deposited in the form of rime or hoar-frost. Before it was known that bodies on the earth's surface became cooler than the surrounding air, it was impossible to understand how the flimsy coverings employed by gardeners could so thoroughly protect vegetables and fruit-trees from the injury of frost. The natives of Peru, having observed that in that country it freezes only when the sky is clear, contrive to create artificial clouds, whenever, from the appearance of the sky, they are led to fear a frost. This they do by setting fire to heaps of damp straw, which raise clouds of smoke over their crops, and, on calm nights, afford sufficient protection.

86. The temperature at which the atmosphere begins to deposit moisture is called the *Dew-point*. The late Professor Daniell invented an interesting little instrument of considerable importance. It is called the "Dew-point hygrometer"—the latter word signifying a measurer of moisture. It consists of a bent glass tube, terminating in two bulbs, one of which is half filled with ether, the whole being free from atmospheric air. In the ether bulb (fig. 6) is a delicate thermometer; a piece of muslin, moistened with ether, covers the empty bulb outside. The cold produced by the evaporation of this ether, condenses the ether vapour inside the tube, and rapidly lowers the temperature of the ether bulb until dew appears on its surface. When

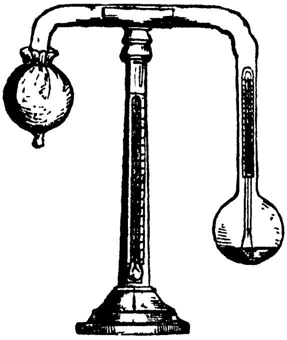

Fig. 6.—DANIELL'S HYGROMETER.

this takes place, the dew-point is read off by looking at the little thermometer.

37. Rain has been already mentioned as a very pure form of water (par. 16). Hence, in falling through the air, it literally washes the latter, and frees it from those gaseous and other impurities which in places contaminate it. These substances it dissolves, and carries through the soil into the circulation of the plants, which employ them for nourishment.

38. When the temperature of the upper regions of the air is below the freezing-point (0° C.), the moisture freezes and falls as SNOW. Whether the snow-flakes are formed at once by the freezing of the moisture in the cloud, or whether the frozen particles unite with a thousand others in their fall, has not been fully ascertained. The exquisitely beautiful forms assumed by the snow-flakes must be closely examined to be fairly appreciated: some of them are depicted in Figure 7 on the next page.

39. The effects of the physical changes of the vapour of the air into liquid water, and solid snow, are of great importance. Whenever a solid melts or is made liquid, and whenever a liquid is changed into vapour, a certain amount of heat is required. And so also, when a vapour turns into a liquid, or a liquid becomes solid, the same amount of heat is set free. In the act of melting, the water which flows from ice is found to have the same temperature as the ice; heat is absorbed. And again, when water is changed into ice or snow, the same amount of heat is set free as was necessary to thaw the ice or snow. Now as 79° C. are required to thaw one pound of ice, so as to change it into water having the same temperature as the ice, so likewise is the same amount of heat (viz., 79° C., or 79 units of heat) set free, when one pound of water is changed into one pound of ice.

The formation of snow is consequently attended by a rise of temperature! A fall of snow produces also peculiar effects on vegetation. From its porous character, the snow in its fall from the sky entangles much air, which assists by its non-conducting power for heat in protecting the tender shoots from the frost. It is also a curious circumstance that the snow contains a larger proportion of oxygen than is found in the atmosphere, which, in melting, it carries to the ground,

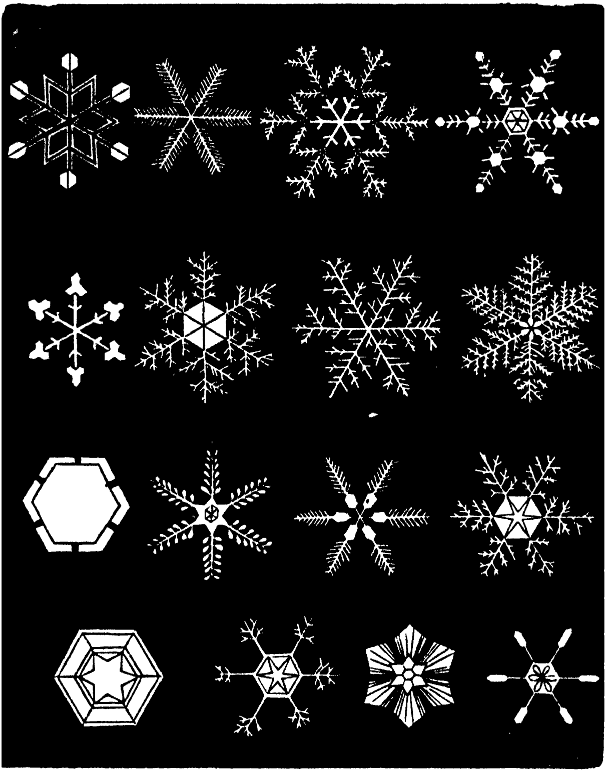

Fig. 7.—SNOW CRYSTALS.

fertilizing the soil by aiding the solvent action of the water upon its most important mineral constituents. A fall of snow one inch in depth affords in melting one-tenth of an inch of water.

40. Of HAIL, another form in which water is condensed from the atmosphere, little is known beyond the fact that electricity always accompanies its production.

41. The fall of hail-stones and of rain illustrates in the most striking manner one of the physical (natural) characteristics of the air; by its resistance to their passage it retards their descent and lessens the force of their fall. How quietly and softly does the rain descend upon the tender foliage of the trees, and the delicate petals of flowers, refreshing, without injuring, their frail structures. In separating from the clouds, the drops fall faster and faster, till the increasing resistance of the air becomes nearly equal to their weight, when they continue to fall at an even rate. The destructive effects of hail-stones are often sufficiently striking; but what incalculable devastation would ensue were the atmosphere to offer no resistance to their descent!

42. Far behind oxygen, nitrogen, and watery vapour in quantity, but always present in the air, is **Carbonic Acid.** There is one volume or measure of carbonic acid in 2,500 volumes or measures of air. Its sources are most numerous, the great processes of respiration, decay, combustion, germination, and fermentation, being each and all productive of carbonic acid gas.

43. Carbonic acid is not an element, but a compound of two elements, **Carbon** and **Oxygen.** One of the commonest forms of carbon is known as charcoal, and whenever charcoal is fully burnt, whether in air or in oxygen, carbonic acid results. As carbon is contained in all combustible matter, it is easy to conceive how every variety of combustion will introduce a certain quantity of carbonic acid into the atmosphere.

44. The blood also contains carbon in union with other elements. Every time a breath is drawn, a portion of the inspired air, but especially of its oxygen,

is taken up by the blood circulating through the lungs, and the air which is returned by expiration is considerably changed. In place of the oxygen which it gave up, it contains a similar quantity of carbonic acid. Breathed air contains 100 times as much carbonic acid as the fresh air before it is breathed. This breathed air will neither support combustion, nor serve any longer for respiration.

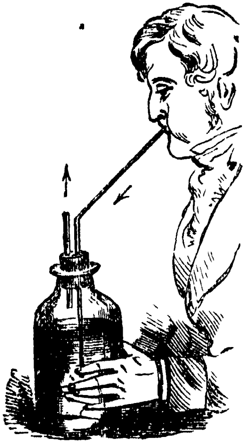

Fig. 8.

If we breathe through a glass tube into a bottle containing lime-water (made by shaking a little slaked lime with water, and decanting the clear liquid) the latter becomes milky from the formation of chalk or carbonate of lime. The act is represented by fig. 8. Now air in its ordinary condition would not produce this change, on account of the exceedingly small quantity of carbonic acid contained in it. Thus is a certain portion of air spoilt by every breath drawn.

45. Germination in this respect is like unto respiration. If some seeds be moistened and placed under a shade containing common air, all the signs of vegetation will soon commence. An examination of the air after the seeds have sprouted will give evidence of a change in its composition; a portion of its oxygen has disappeared, and a corresponding volume of carbonic acid has been produced. This fact explains the necessity of oxygen in water for the germination of aquatic plants. The presence of oxygen is as favourable to germination, as that of large quantities of carbonic acid is unfavourable; hence the process is hastened by the introduction into the soil of slaked lime, in order to absorb the carbonic acid as fast as it is produced by the sprouting seed.

46. That carbonic acid is evolved in the process of decay is easily proved. Its deleterious effects are sometimes witnessed in a person sleeping upon dead leaves ; and it is found that the air, in a confined space, over decaying matter, soon ceases to have the power of supporting combustion. If this were not so, and did not leaves and plants in their decay resolve themselves into gases, what would become of all the refuse vegetable and animal matter, the accumulation of ages of living and dead organized beings?

47. This question at once suggests another. Since carbonic acid is always present in the air, being continually produced by respiration, combustion, and the like, at the expense of the oxygen, how does it happen that the oxygen does not unduly diminish, and the carbonic acid increase? It suggests an inquiry into the manner in which plants obtain the **Carbon** which they require for their growth.

48. A very simple experiment will prove the presence of carbon in every part of a plant. The charring of a leaf, stalk, or piece of wood is due to the presence of carbon, which separates as charcoal, and which is not burnt (or oxydized) so readily as those other constituents of plants which contain hydrogen. As this carbon is an elementary substance, and therefore cannot be produced by the plant itself, it must be derived from some external source. Now, the only sources from which the constituents of plants are derived, are the *soil*, *water*, and the *air*. From the soil come all its mineral ingredients, or all those which are already, so to speak, burnt or oxydized, in fact, all that which remains in the solid state after the plant is completely burnt—its *ash*. This mineral matter or ash, however, rarely exceeds 1½ per cent. of its weight. Again, great as is the influence of water, or hydrogen oxide, on the plant, both as forming one of its chief constituents and as contributing largely in other ways to its growth, it can only furnish the two elements, *hydrogen* and *oxygen* (page 7).

49. So, then, the principal part of the **Carbon must** come from the air, and **Carbonic acid** is the only **compound** in the air which **contains** it. The leaves have the power of decomposing carbonic acid under the influence of the sun's light; they keep the **Carbon** for their own use, and restore the Oxygen to the air.

50. The presence of light is essential. DE SAUSSURE found that young plants (or a sprig of mint, fig. 9) under the influence of solar light throve in an atmosphere containing one-twelfth of its bulk of carbonic acid, and that their growth was evidently more vigorous than in common air; while, at the conclusion of one experiment, he found that almost the whole of the carbonic acid had been replaced by oxygen. On the other hand, if the plants were kept in the shade, he found that the smallest addition of carbonic acid to the atmosphere was injurious to their growth. For the above reason this appropriation, or, as it is called, assimilation, of carbonic acid ceases at night-time; oxygen is no longer exhaled from the leaves of the plants, but the opposite chemical process takes place similar to that which occurs in animals. Oxygen is inhaled by the leaves, and carbonic acid formed at the expense of the carbon contained in them; and the carbonic acid so formed is kept back, either in part or entirely, according as the green portion of the leaf is more or less plentifully supplied with water. This absorption of oxygen (respiration) appears to take place equally during the day, but it is then overpowered by the opposite process—the absorption of carbonic acid.

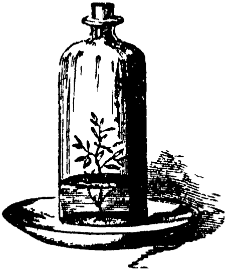

Fig. 9.

51. Owing to its solubility in water, some of the carbonic acid of the atmosphere is washed by every shower into the soil, and is thus conveyed to the plants

by another channel, viz., through their roots. This solubility of carbonic acid enables aquatic plants to get their due supply of it, which they require as much as land plants.

52. It is evident that the carbonic acid of the air would be rapidly exhausted by the constant processes of vegetation, were there not some equally continuous source of supply. Such a source, however, is found in the respiration of men and animals, and in the decay of both animal and vegetable matter.

53. Thus there is a mutual interchange of kind offices between animals and vegetables, by which the purity and the uniformity of the air is maintained, the one supplying to the air what the other requires for its existence. Men and animals respire oxygen and exhale carbonic acid ; plants absorb carbonic acid, keep back the carbon, and give out oxygen.

54. To the constituents of the air already enumerated, viz., *oxygen*, *nitrogen*, *watery vapour*, and *carbonic acid*, must be added **Ammonia**, which, in combination with carbonic acid as **Ammonium Carbonate**, is always present, although only in minute quantities. One million parts of air contain only about one-quarter of one part by day, and about twice that quantity by night. The comparative smallness of the quantity present by day is due partly to its consumption in the nutrition of plants, and partly to the fact that the ammonia which accumulates in the day and night is dissolved and deposited by the morning mists. At all times, and from many sources, ammonia is given out to the air. There can be neither decay nor putrefaction without its development, nor can any material containing nitrogen and hydrogen be burnt without its formation. It is also given out in respiration and in perspiration. Not that it is ever generated in any of these processes in equal quantity with carbonic acid, inasmuch as, under the circumstances most favourable to its production, as in respiration, it is never produced in sufficient quantity to allow of its recognition by its familiar odour of

hartshorn. Nor can it ever accumulate like carbonic acid, as its very easy solubility in water occasions its constant removal from the air by every passing shower or fall of dew.

55. Ammonia is a compound of two elements, *nitrogen* and *hydrogen;* from it plants derive their nitrogen, without which they would be useless as food for animals, whose flesh contains abundance of nitrogen. Though surrounded by air, which contains 79 per cent. of nitrogen when freed from moisture, all plants would languish for want of it, were it not for the ammonia also present. The plant can make no use of nitrogen in its simple form; it can only obtain it from some compound containing nitrogen. Hence the value of manures is for the most part in proportion to the amount of ammonia which they contain, or afford. How admirable, therefore, is the provision that decay and putrefaction should thus minister to the life and vigorous growth of fresh vegetation!

56. There is yet a third form in which nitrogen is sometimes contained in the air. In rain-water, after thunderstorms, **Nitric Acid** can nearly always be discovered. It has been proved by experiment, that the mere passage of sparks from the electrical machine through the air is sufficient to cause some of the nitrogen to unite with oxygen and with water, to produce nitric acid or **Hydrogen nitrate**, as it is generally called. Indeed it was in this manner that the compound nature of nitric acid was first shown by Cavendish in 1785. As a manure, hydrogen nitrate diluted with much water, is as valuable for its nitrogen as is ammonia. (Other salts of nitric acid are also very important in this respect. Nitrate of sodium is the commonest salt of nitric acid, and is much used as a manure.)

CHAPTER III.

TRACES OF IMPURITIES IN THE AIR—ON THE DIFFUSION OF GASES—THE WEIGHT OF THE AIR—THE BAROMETER—THE NATURE OF CLOUDS—CLOUDS, A KIND OF BAROMETER.

57. We have already learnt that the atmosphere is a mixture of oxygen and nitrogen, together with more or less of the vapour of water, a very small quantity of carbonic acid, and a mere trace of ammonia and of nitric acid.

58. But, inasmuch as the atmosphere surrounds the earth, everything that is volatile may find its way into the air, and form an occasional constituent.

59. Whenever vegetable matter decays in presence of much moisture, **Marsh-gas** (par. 115) is always generated; so that, by some observers, this gas is added to the number of constant ingredients of the atmosphere. It is a compound of carbon and hydrogen, and is largely a constituent of coal-gas.

60. Among the most curious occasional constituents of the air, is a peculiar modification of oxygen, which is known by the name **Ozone.** Although possessed of very different properties, it is only oxygen under different physical aspects. It was discovered by Schoenbein in 1840, and was called ozone on account of its marked odour. Those who are acquainted with the smell produced when an electrical machine is put in action, will know what ozone is like, when they are told that the peculiar smell is due to ozone. Although ozone is never present in the air in anything like sufficent quantity to be observable by its odour, yet it is often largely produced during storms; some compounds containing oxygen are probably decomposed, and the oxygen set free has the properties of ozone. It is a very powerful disinfectant (par. 170), owing to its oxydizing properties. As it is perfectly insoluble in water, the

air which passes over seas does not lose its ozone. When it meets with putrescent matter, ozone oxydizes it, enters into composition with the hydrogen of the putrescent matter and disappears.

61. In large cities the air is also always more or less contaminated by the various gases evolved from putrefying or decaying animal and vegetable matters, from the burning of coal, and from the numerous chemical processes carried on in such places.

62. Common coal always contains **Sulphur** united with **iron,** as iron-pyrites. When this is burnt, both the sulphur and the iron oxydize. The iron remains as oxide of iron, or rust, in the ash, and the sulphur goes into the air as **Sulphurous acid** gas. The latter is also produced whenever sulphur or brimstone is burnt, and is well-known by its odour as that of the burning brimstone match.

63. From drains and sewers, **Sulphuretted hydrogen** (or rotten egg gas, as it is sometimes called, because it is also given off from rotten eggs) is often set free. Mercifully, the odour is so offensive that it is at once detected. Its injurious effects are easily prevented, as it is quickly decomposed by chlorine. But, otherwise, so fatal is it, that its presence in the air, to the extent of $\frac{1}{1500}$ of its bulk will destroy the life of small birds, while a horse will die where the air contains $\frac{1}{250}$ of its volume of this gas.

64. But setting aside such minor differences as are occasioned by the presence of slight casual impurities, how does it happen that, as regards its chief constituents, the air maintains its composition so uniformly in all open places? Samples brought from distances far apart from each other, exhibit a perfect sameness of composition; and to such an extent is this the case, that the oxygen and nitrogen of the air were long believed to be chemically united.

65. And yet we know that this is not the case; that the **air is not** a compound. In a chemical compound the elements lose their individual characters; in a

mixture, these are retained. Oxygen is a supporter of combustion; so is the atmosphere. Oxygen supports combustion far better than the air; the air contains four times as much of nitrogen as it does of oxygen, and nitrogen does not support combustion. Oxygen is more soluble in water than nitrogen; if air be shaken with water, the latter dissolves oxygen in proportions twice as great as it does of nitrogen. Air, therefore, must be a mixture, and this, too, in spite of the fact that all the gases contained in the air are of different densities, and that there is a far greater difference between the respective weights of nitrogen and carbonic acid, than between oil and water.

66. The subject of this intermixture of gases of different densities has been thoroughly examined by the late Professor Graham: it is called DIFFUSION. Owing to the absence of cohesion between their particles, vapours and gases mingle very freely and completely—a peculiarity of such mixture being, that they never again separate into their component parts. To such an extent is this tendency to mingle carried into action, that if two gases, say hydrogen and oxygen (the latter being sixteen times heavier than hydrogen), be allowed access to each other through a tube several feet in length, as in fig. 10, they will be found to have mixed thoroughly in the course of a few hours.

[The rapidity with which such diffusion takes place, is inversely proportional to the square root of the densities of the different gases. Oxygen being sixteen times heavier than hydrogen, it follows that only one volume of oxygen would diffuse itself in the same time that four volumes of hydrogen would be able to do so.]

The diffusive power of gases is of the utmost importance. Were it not for this law, the carbonic acid evolved

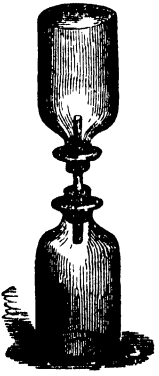

Fig. 10.

in such large quantities in our large towns would, from its intrinsic weight, collect, and speedily destroy their inhabitants. The foul and noxious gases constantly arising from the numerous operations of a large city would spread disease and pestilence around it. But for this, the perfumes of flowers would fall from their own weights on the senseless earth, instead of rising and diffusing a sense of joy and gladness in our hearts.

67. In common with every form of matter, the atmosphere is possessed of weight. This property was first demonstrated by the celebrated Italian Torricelli, whose attention was called to it by the following circumstances. In sinking a well at Florence in 1643, it was found that, after sinking a certain depth, the common suction-pump ceased to bring water to the surface. It had been previously known that when a tube was dipped in water and the air above it withdrawn, the water would rise to a very considerable height; but the only explanation of this phenomenon that was offered, was the vague assertion "that nature abhorred a vacuum," and that the water rose in the tube to fill the vacuum caused by the exhaustion of the air.

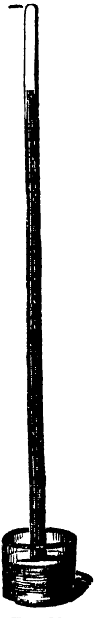

Fig. 11.—THE BAROMETER.

68. The attention of Torricelli having been called to the fact that the water in the suction-pipe of the pump would not rise beyond a height of 34 feet, it occurred to him that its rising at all was to be attributed to the pressure of the atmosphere outside the pipe, forcing the water to occupy the vacuum (space free from air), caused by the exhaustion within it. Torricelli presumed that, as the volume of water was sustained by the pressure of the air, the two must exactly balance each other; and, therefore, that a volume of water 34 feet high must be of equal weight with a similar

column of the whole height of the atmosphere. Supposing this to be the case, then a denser fluid exchanged for the water ought to rise in the exhausted tube less than the water; in fact, in exact proportion to the greater density of the fluid employed. To prove this theory, Torricelli filled a glass tube (fig. 11), three feet long, and closed at the lower end, with mercury, and inverted it in a vessel containing the same liquid. The mercury immediately sank 6 inches in the tube, leaving a column 30 inches in height. Now, as the weight of the mercury is 13½ times greater than that of the water, the truth of his opinion was fully proved, viz., that the weight of a column of the atmosphere was equal to a similar column of water 33¾ feet, or of mercury 30 inches high!

69. In 1648, Pascal repeated Torricelli's experiment, and varied it by the employment of other liquids of different densities. But, as many still affected to doubt whether the rise of the fluid was really owing to atmospheric air, he determined to bring the question to a definite issue. Having filled two tubes with mercury at the base of the Puy de Dome, a mountain in Auvergne, he inverted them as in the previous experiment, and saw that the mercury stood at the same height in both. One tube he left at the foot of the mountain, and carried the other to the summit. As he ascended the mountain, the mercury fell steadily in the tube, till, on reaching the summit, it stood at $3\frac{3}{10}$ inches lower than it did at the base! On descending, the mercury steadily rose till he reached the point whence he started, when the column had returned to the exact height at which it originally stood. He was forced to the conclusion, that, as in ascending the mountain, the atmosphere above him was diminished in proportion to the height ascended, its power of supporting the mercury was diminished in like proportion, and therefore the column in the tube must always represent the exact weight of the overlying atmosphere.

70. Thus was invented that most valuable instru-

ment, the **Barometer** (from the Greek *baros*, weight, and *metron* a measure). As the range of the rise and fall of the mercury, at the level of the sea, never exceeds or even reaches 4 inches, the division of the scale is made only on that part of the column between 27 and 31 inches.

71. The vacant space above the quicksilver, in the closed end of the tube, is called the Torricellian vacuum, from its having been observed by Torricelli to be free from air.

72. The mean height of the barometer is about 30 inches at the sea-level. As the height of the column of mercury is somewhat affected by its different expansion at different temperatures, it is necessary, when accuracy is required, to calculate and make allowance for the expansion. On account of the cohesion of the mercury, there is a depression in the tube which renders a correction necessary in reading off the height of the column, unless the barometer-tube be above a half-inch in bore, when it may be disregarded. The reading is from the surface of the mercury, from the top of the convexity. Before taking an observation, the instrument should be gently tapped to prevent the adhesion of the mercury to the tube, and the eye of the observer should be on a level with the top of the column.

73. There are many modifications of the barometer, but space will not allow of any mention being made of them. For the most part, variations in the weight of the atmosphere, as indicated by the fluctuations in the barometric column, depend upon differences in its moisture and heat.

74. In virtue of the perfect elasticity of the atmosphere, by which its particles tend to repel each other, it is enabled to adapt itself exactly, under any degree of pressure, to the space which it is required to fill. If, therefore, the pressure is altered, the volume of the air is altered too. In the language of science, the volume occupied by a gas is inversely proportional to the pressure to which it is subjected. If the pressure be

doubled, the volume of a gas is halved; if the pressure be halved, the volume of a gas is doubled. This great fact in physics is known as the law of Marriotte. A necessary consequence of this law of elasticity, is the increasing rarefaction of the air as we ascend mountains. If we suppose the atmosphere to be divided into strata or layers of equal weights, the upper stratum will press downwards with its own weight only; the second, with its own weight increased by the weight of the first; the third stratum will have to support its own weight added to that of the two upper strata, and so on. Thus, the density of the atmosphere must decrease in equal ratios in ascending through equal heights, and is therefore capable of measurement by a corresponding fall of the barometric column.

75. As the bulk of air is so much affected by pressure and heat, its density is always calculated at a fixed temperature and pressure.

[The bulk of air increases $\frac{1}{273}$ of its volume for each degree Centigrade. Thus, 273 volumes of air, if heated one degree, would enlarge to 274 volumes. In many English works the density of a gas is given at a temperature of 15°.5 C., and at a pressure of 30 inches barometer (30″). One hundred cubic inches of dry air weigh 31·0117 grains. In France, the height of the barometer is given in millimetres, or thousandths of a metre. A metre is 39·37 inches. Our 30″ bar. correspond to 760 millimetres.]

76. The weight of a column of mercury 30″ in height, and covering one square inch, amounts to 15 lbs. As the air presses upon the earth's surface with that force, it follows that objects of all kinds, at the sea-level, have to support an average pressure of 15 lbs. on each square inch of surface. Taking the surface of a man's body at 2,000 square inches, the pressure upon it must amount to about 13½ tons; yet, owing to the perfect equality of its pressure, and to the fact that every cavity within him is expanded by aid of the same elastic force, he is enabled to sustain this enormous

load not only without inconvenience, but generally without even a consciousness of its existence. From the perfect mobility of the particles of air, the force of its pressure is evenly communicated throughout, and exerted equally in all directions.

77. **Clouds** are nothing more than masses of mist in the higher regions of the air. Now there are three causes for the more frequent formation of clouds in these higher regions, than near the ground. In the first place, the gradual rarefaction of the air as it ascends, at last cools it down by decreasing its capacity for heat to its dew-point (par. 36): that is, to the temperature at which it is obliged to part with some of its moisture. Secondly, it is chiefly in the upper regions that different currents of air meet and mingle. If two currents of different temperatures, both charged with moisture, meet, although their temperature becomes uniform, the mixed air at this mean temperature can no longer contain all the moisture, and some of it must separate; or, a large body of air may be cooled down in passing from a warm climate to a cold one, and the result is the same. Thirdly, mountain-tops, by their cooling influence, condense the vapour in the air that sweeps over them. In common language, they attract the clouds; but they do not really attract them, but cause them. Hence, mountainous regions are those in which most rain falls.

78. The height at which the clouds are found is very various. Thin light clouds soar above the loftiest mountains, while thick and heavy clouds approach very near the low lands. Their average height may be about two miles and a-half, and they are not supposed to rise more than double that height above the earth.

79. Their size is very varied; some extending over an area of twenty square miles, with a thickness of a thousand feet, while others are of very insignificant dimensions.

80. The effect of clouds on atmospheric pressure, that is, on the indications of the barometer, depends on

the circumstances accompanying their formation. The weight of an atmosphere of vapour is but $\frac{3}{5}$ of that of an equal bulk of dry air. It is clear, therefore, that all things being equal, the more vapour the air contains, the lighter it must be! Suppose, then, that a body of dry air is invaded by moist, with the formation of cloud ; a fall of the barometer must take place. In the opposite case of a body of cold dry air coming to the moist, a different effect will be produced on the barometer. But, in either case, the change must extend over a considerable district, to cause an appreciable change of atmospheric pressure. Mere slight local causes, such as give rise to the lighter form of clouds, can have no such influence. And, of course, a long continuance of cloud, unaccompanied by changes in the moisture of the air, is quite compatible with a steady barometer.

81. There are three great and characteristic forms of cloud,—the Cirrus, Cumulus, and Stratus.

82. The lightest of clouds, that, therefore, which ascends to the greatest height, and is seen at almost all seasons of the year, is the **Cirrus.** The various forms of cloud are represented in fig. 12.

From its height, it is often lighted up by the rays of the rising or setting sun, while the lower clouds are in darkness. It lies in patches on the deep-blue sky, while its motion is generally slow, and its appearance, fibrous, delicate, and thread-like.

83. The **Cumulus** is the cloud of spring and summer. Formed in the day-time, its density keeps from the earth the sultry rays of the noontide sun. Towards evening it gradually disappears, owing to the increased temperature of the superior strata of air. Its form, when viewed sideways, increases from above in dense, convex heaps; in hot weather it often appears stationary, with a flattened base, its rock-like summits showing with a silvery light. When the cumulus increases after sunset and shines with a ruddy hue, it indicates the coming of a thunderstorm.

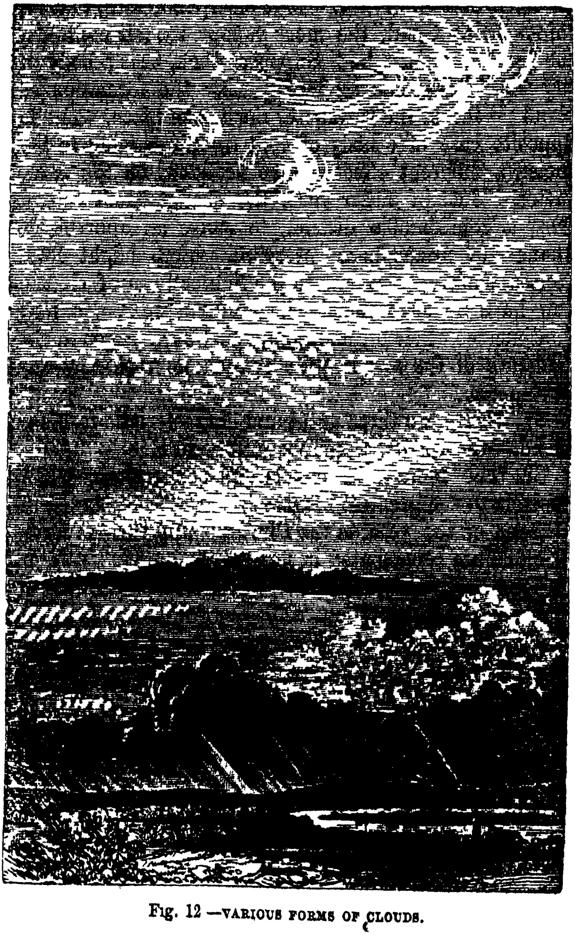

Fig. 12 —VARIOUS FORMS OF CLOUDS.

84. The **Stratus** is the horizontal sheet of cloud nearest to the ground. It occurs chiefly at night, or in the cool of a calm evening. It frequently appears on fine autumnal mornings and evenings, sometimes resting on the ground, sometimes hovering a few feet above it. The Stratus deposits moisture which is often cooled into hoar-frost, rendering the face of nature exquisitely beautiful; it is also the cause of the mists which are scattered by the rising sun. It is most frequently seen from September till January.

85. There are several well-defined modifications of the three forms of cloud already described, which can be recognized in cloud-land.

86. The **Cirro-stratus**, like the Cirrus, is to be found in the higher cloud-region, and is to be seen at all seasons. Sometimes it appears dark and threatening; at others, attenuated. The Cirro-stratus accompanies a fall in the barometer, and is the precursor of rain and wind.

87. The **Cirro-cumulus** is often formed from the Cirrus. It is the warm-weather cloud, and attends a rising barometer. When seen alone in the higher regions of the atmosphere, it assumes a dappled appearance, and is commonly known as a mackerel-back sky. More frequently it bears the form of small, round, patches of cloud, having between them openings of clear, blue sky. The glorious crimson, contrasting with the delicate blue of a fine sunset, and the rich golden hues pervading the bright blue of a sunrise in summer, are due to the Cirrus and Cirro-cumulus.

88. The **Cumulo-stratus** is the most dense form of cloud, and causes, in passing, a sensible reduction of temperature. It is made up of the Cumulus, the Cirro-cumulus, and the Cirro-stratus. It forms the thunder-cloud and indicates changes of wind, hail, and storm.

89. The **Nimbus** is a modification of the Cumulo-stratus cloud seen in profile during a shower, and is never seen with a high barometer. Its attendant is the glorious rainbow. **Scud** is like Stratus, of the clouds

nearest the earth. It is common during the winter months, and is witnessed more frequently after rain, than at other times.

90. The clouds may be divided into two groups: the first comprising Cirrus, Cirro-stratus, Cirro-cumulus, and Scud, which descend, producing rain and wind; the second, including Stratus and Cumulus, which ascend and are the attendants of fine weather.

91. In the registration of atmospheric phenomena, it is usual to record the amount of cloud visible at the time of observation. A clear sky is marked 0 and a cloudy sky 10, the degrees of cloudiness being indicated by the intermediate figures.

92. The sky is most free from cloud at night and most covered at noon. In our climate, three-fourths of the sky are generally covered during November, December, January, and February; and in the finest months of the year three-fifths of the sky are clouded over (Belville).

CHAPTER IV.

THE NATURE OF BURNING—THE CHEMISTRY OF COAL AND OF A COAL-FIRE—DIFFERENCE BETWEEN COAL AND COKE—THE NATURE OF THE GASES IN COAL-GAS.

93. It has been already stated that the great supporter of combustion is Oxygen: that under ordinary circumstances, burning bodies obtain their Oxygen from the air; that the intensity of the combustion is in proportion to the amount of Oxygen present in a free state; that therefore it is most energetic in pure Oxygen,—so energetic, in fact, that, for the ordinary operations of nature, it requires to be restrained by the dilution of the Oxygen of the atmosphere with four times its volume of Nitrogen.

94. The exact composition of the air, as far as its most important constituents are concerned, is seen to be as follows :—

Oxygen	20·61
Nitrogen	77·95
Watery vapour	1·40
Carbonic acid	0·04
	100·00

95. **Combustion** is a simple chemical process, consisting in the union of the body to be burnt with Oxygen. After the union, the body so burnt is said to be oxydized. And when any substance has once entered as fully into combination as is possible, it cannot be either set on fire or burnt: it is then both uninflammable and incombustible. It has been already burnt as much as is possible. Now as combustion consists in the union of any substance with oxygen, it is clear that the substance, after it has been burnt, must be increased in weight by just so much as the weight of the Oxygen which it has absorbed. To speak of the destruction of a body by burning, cannot therefore be correct, for all matter is indestructible. The body is not destroyed, but has only changed its form. This is clear enough in such a case as the burning of Phosphorus; there we see, and handle, and easily collect and weigh, the Phosphoric acid produced. But it is not so clear in the case of a candle, because the new substances into which they are transformed are gaseous and invisible, and are dispersed into thin air. We can, however, collect and weigh these gases, and prove that in their case also, the burnt substances have actually increased in weight (par. 130).

97. Combustion is always accompanied by a development of heat, and generally by light. Every combustible substance has a certain fixed temperature at which it burns in air, but this temperature differs greatly for different substances. Some, such as the elements Phosphorus, Iron, and Lead, when in a fine state of division, are so eager for Oxygen, so anxious to change their single condition, that they take fire the

moment they are exposed to the action of the air; others at a temperature but slightly above that of summer heat; while others again can only be induced to change their state by the urgent persuasion of intense heat. Neither of these classes of substances could answer the purposes of fuel; the one would burn too rapidly, the other too slowly to meet the requirements of life. But there is a large class of bodies, principally of vegetable origin, which possesses the necessary characteristics.

98. The only point in which these bodies agree, whatever may be their visible properties, is in containing both **Carbon** and **Hydrogen,** the leading feature being the very large proportion of Carbon.

99. As no vegetable matter can be formed without the help of certain mineral constituents, which are wholly unalterable by fire (par. 48), it is clear that Charcoal from wood is not Carbon in a pure form. And so the purest Charcoal leaves an ash when burnt with full access of air.

100. It is, however, with **Coal** that we have to deal, a substance of well-known vegetable origin. In it we see the remains of a vegetation which covered the earth in long bygone ages. The former existence of surface-land has been proved by the occurrence of numerous, upright, fossil trees, with their roots terminating downwards in seams of coal. Our coal-mines furnish almost a complete fossil Flora; a history of many of the now lost species which once decorated the face of the earth. There is a great resemblance between the plants of the coal-formation, and the Flora of New Zealand. The botany of those islands is characterized by abundance of ferns, one hundred and forty species of which are already known, some attaining to the size of trees. Another point of resemblance is the prevalence of the Fir tribe. A large proportion of the purest kind of coal has been formed from plants which grew on the spot, by a process similar to that which is now seen at the bottoms of marshes, lakes, and rivers, in the

formation of peat. The vegetable matter, submerged in water, undergoes decomposition, losing its Water and some of its Hydrogen, and leaving its Carbon behind: this is subsequently covered by accumulations of clay and sand, which, in process of time, harden into slate and gritstone. The pressure of the deep overlying strata has not only prevented the evolution of gas, thus giving the coal the property of burning with flame, but has destroyed most traces of vegetable structure, and given to the Pit-coal the close and compact quality of stone.

101. The several varieties of Coal differ greatly in appearance and composition. All coal consists chiefly of Carbon with a somewhat varying per-centage of Hydrogen, Oxygen, and Nitrogen, and with very variable quantities of Sulphur and of Ash.

102. The principal varieties of Coal in common use are five:—cubical coal, fat bituminous coal, anthracite, steam-coal, and cannel coal. Anthracite contains more Carbon than any other kind. For the same reason it burns without flame, and, of course, never smokes; it gives out much heat, and leaves but little ash. Cannel or gas-coal burns with a brilliant flame, because it contains so much Hydrogen which unites with the Carbon: it derives its name from the practice among the Scotch farmers of burning it for its light, instead of candles, or, as they pronounce it, "cannels."

103. **Lignite**, or **brown coal**, which is used as fuel in some parts of the world, rarely occurs in extensive fields as does pit-coal. It has usually a brown color, burns with a dark smoky flame, and a very disagreeable odor; it consists, in fact, of vegetable matter very little altered.

104. **Peat** consists also chiefly of the remains of plants which have undergone comparatively little change.

105. **Wood** may be said to contain nearly equal weights of Carbon united with Hydrogen and Oxygen in the same proportions in which they are found in water. From this statement it may be inferred, that

wood fires will not only burn with much flame and little smoke, but will also give out intense heat and consume very fast. There is also a very peculiar odor which usually accompanies the burning of wood.

106. Combustible as are all kinds of coal, they must nevertheless be heated to some extent before they will inflame. For domestic purposes this heating is accomplished by the use of the more readily combustible materials, paper and wood. These are laid in the grate, and the coal heaped on them in such a manner as to allow the air free access to them. When the coal is heated below redness by the lighted wood, its Hydrogen unites partly with its own Oxygen and partly with the Oxygen of the air, and escapes up the chimney in the form of steam. The heat being at first below that at which Carbon ignites, a quantity of it passes off unconsumed as smoke. Soon, however, the heat increases by continued chemical action ; gases are formed which kindle on contact with the air, and burn as long as the coals continue to supply volatile matter. After the flame has ceased, the coals retain their glow as long as any Carbon is left, and at length nothing remains in the grate but the incombustible ash.

107. As to the temperature of a fire, a dull red-heat, visible in day-light, is probably equal to 525° C., a full red-heat to 1,000° C., and an orange heat to 1,100° C.

108. The chief results of the full combustion of Coal are, Water and Carbonic acid (par. 151), with smaller quantities of Sulphurous acid (par. 62), and still less of Ammonia (par. 54).

109. The waste of fuel that takes place when much of it escapes in the form of smoke is mainly due to the improper supply of air, and may be to a great extent prevented. The very common practice of heaping up a fire with fresh coal when it has burnt low is objectionable, because by this it is so much chilled that the fuel, instead of burning, goes off in the shape of unconsumed smoke and gas. In a good

grate all the gases and vapours are carried up the chimney, upon the draft or current in which, the more or less perfect combustion of the coal depends; for, when a body is heated, it instantly causes motion in the particles of air by which it is surrounded. If, for example, a cannon-ball were heated to redness and placed on a stand, as in fig. 13, it would set the surrounding air in quick movement. A stream of hot air would rise up and a stream of colder air continually take its place. A fire thus serves the purpose both of ventilation and of warming; the larger the fire in a room, the more necessary it becomes to keep it supplied with fresh air from without; the draught in the chimney depending entirely on the replacing with colder air the rarefied air that ascends the flue.

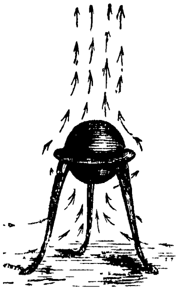

Fig. 13.

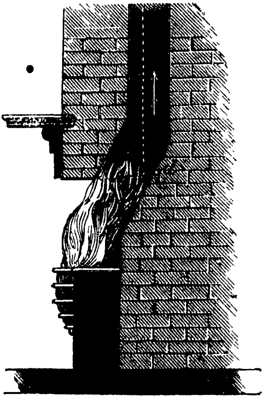

Fig. 14.

110. The reason then why an open fire-place assists in the ventilation of a room ought now to be quite clear. Bodies expand by heat; the air over the fire consequently becomes lighter, and ascends (fig. 14), its place being taken by cold air drawn from the room. Thus, by the successive expansion and ascent of fresh portions of air, a perpetual upper current, as indicated by the arrow, is maintained in the chimney, by which the fire is supplied with the fresh air it requires for the combustion of the fuel. The best bellows for a flagging

fire, is a piece of paper sufficiently large to close the space between the fire and the chimney, compelling all the air to pass from below directly through the fire. In cases where it is necessary, such as in rooms where gas is burnt, this current may be turned to further account in ventilation, by the introduction of a properly-constructed valve at *a*, such as an Arnott's ventilator. The air of the room, as it becomes spoilt by respiration and combustion, rises to the ceiling, and is drawn by the current through the ventilator up the chimney. These currents may be readily shown by a very simple experiment. If a chimney-glass be placed upon the table over a small lighted taper, it will be extinguished; but if the chimney-glass be divided vertically by a card, as in fig. 15, the taper will continue to burn. The air heated by the flame will ascend by one division, while fresh air to supply its place will descend by the other. Such an arrangement is of common application in the shafts of coal-mines, one of which is made to act as an ascending, the other as a descending. A moment's consideration of fig. 16 will make the proceeding clear. The cold air descends by the glass tube *a*, and the vitiated air escapes by the tube *b*.

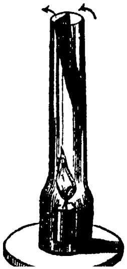

Fig. 15.

111. The effect of heat on any substance depends then upon the presence or absence of **air,** that is, of **Oxygen.** The results of heating coal in air have been sufficiently explained. But, if it be heated in the absence, or with very slight access, of air, by a kind of smothered combustion, as in the manufacture of charcoal, the coal is much altered, but not burnt. Gas is driven off, and the greater part of the Carbon remains unburnt as **Coke**—a variety of Carbon, containing in addition all the ash of the coal. Coke is a good conductor of heat, and therefore more difficult to

ignite than coal, but it is well adapted for fuel, as it burns without smoke and with an intense, steady heat. For use in locomotives, coke is largely manufactured by heating the coal in ovens constructed expressly for the purpose.

Fig. 16.

112. The great difference, then, between coal and coke, is the presence of volatile matter in the former, and its absence in the latter. The power of coal to burn with flame depends upon this volatile matter, which on the application of heat is converted into gas. The **manufacture of Coal-gas** is at present a trade of great importance. The Coal is placed in closed, oblong cylinders of cast-iron, called Retorts, which are ranged in furnaces to keep them at a red-heat, the volatile products being conveyed by pipes, in connection with the retorts, to a condensing vessel kept cold by immersion in water. Here all the condensible vapours, such as **Water, Tar,** and **Ammonia,** together with other impurities are kept back; and the Coal-gas, still very impure from the presence of Carbonic acid and Sulphuretted hydrogen, is passed over Lime, in vessels called Purifiers. In this process the lime unites with, and retains, the Sulphur of the Sulphuretted hydrogen, and the Carbonic acid, but does not act on the Gas, which, further purified, is then passed into Gas-holders, where it is stored for subsequent distribution, by means of iron pipes, to the places where it is required for use.

113. For gas-illumination, the value of the coal is proportionate to the quantity of **volatile matters** which it disengages at a red-heat.

114. Coal-gas is a mixture of several gases, the most important of which are the two Hydro-carbons, Light and Heavy Carbonetted hydrogen.

115. **Light Carbonetted hydrogen** is the principal component of coal-gas. In many coal-mines it is also

found abundantly collected between the seams of coal, escaping from which, it mingles with the air of the mine, and is the common cause of fatal accidents by its explosive inflammation. It is known to miners as Fire-damp, and Wild-fire. It is likewise evolved in the decay of moist vegetable matter; and, as decay, like life, is in perpetual activity upon earth, the gas is generally contained in the air (par. 59). It may be readily obtained by stirring the mud at the bottom of stagnant pools (whence it has the name of marsh-gas), and collecting it as it escapes in an inverted bottle full of water. This marsh-gas burns with a yellowish-white flame. If mixed with 10 measures of air (or 2 measures of Oxygen) it explodes with violence on the application of flame. As it is a compound of Carbon and Hydrogen, the sole products of its combustion in air are Carbonic acid and Water (par. 154).

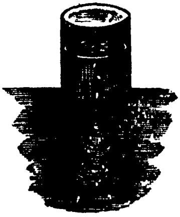

Fig. 17.

116. **Heavy Carbonetted hydrogen** is likewise contained in Coal-gas, and is, indeed, its most important constituent for the purpose of illumination. It burns quietly, with a white light, when set on fire; but, when previously mixed with 15 measures of air (or 3 measures of Oxygen), it detonates with great violence on the approach of flame (par. 155).

117. **Carbonic oxide** is also, to a lesser degree, a constituent of coal-gas. This gas is produced abundantly in the open fire, and is often seen as a blue flame flickering over burning coke and coal. It contains less Oxygen than Carbonic acid, and therefore, as it is not completely burnt, it may be kindled. When fully burnt, it becomes carbonic acid. Carbonic oxide is also abundantly produced in the combustion of charcoal in stoves. It is a very poisonous gas, and is often the cause of fatal accidents when respired.

118. Of course a small quantity of **air** is always present in Coal-gas; also some **Hydrogen.** But as all the gases hitherto mentioned as present in coal-gas are inodorous, whence does it derive the peculiarly offensive smell by which its escape may always be recognized? The odour is partly due to the presence of minute quantities of **Benzol** and of **Naphthalin**; partly to the presence of **Carbonic sulphide.**

119. The removal of the odorous principles in coal-gas offers special difficulties, and it may be doubted whether it is desirable that they should be completely got rid of, considering that the strong smell is an excellent safeguard against accidents, and that well-made gas-fittings, in good order, are amply sufficient to prevent its escape. Apart from this, however, it may be safely asserted, that the purification of coal-gas could with propriety be carried considerably beyond the present practice.

CHAPTER V.

THE NATURE OF FLAME—BODIES INCREASE IN WEIGHT WHEN THEY ARE BURNT—THE BLOWPIPE FLAME—THE DAVY-LAMP—DIFFERENT KINDS OF GAS-JETS—CANDLES. USE OF WICKS—STEARIN AND PALMITIN—WAX—CARBONIC ACID AND WATER ARE FORMED IN THE BURNING OF CANDLES AND THROWN INTO THE AIR.

120. In the preceding Chapter we have learnt that the difference between coal and coke, the one burning with flame, the other without, depends on the presence or absence of gas. The removal of the gas prevents the formation of flame.

121. What, then, is **flame**? Flame is only **burning gas.** This explanation was at one time thought to be with-

out application to the flames from solid and liquid bodies, as candles or oil. But oil, when heated, is readily decomposed and changed into gas; and that the same is true of a candle, is proved by a very simple experiment with which every one is familiar. If a candle with a glowing wick is blown out, there rises from it, for a few seconds, a small cloud of smoke, which may be lighted, even at a distance from the candle. What is this but gas? Flame, then, is burning gas. And inasmuch as combustion is the result of the union of the gas with the Oxygen of the air, it is clear that the gas can only burn when it comes into contact with this Oxygen—that is, at the surface.

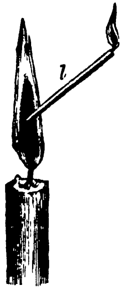

Fig. 18.

122. Hence flame is hollow: it is a luminous envelope to a quantity of gas. The hollow structure of flame may be readily shown by experiment. By inserting into the flame of a candle *a*, one end of the glass-tube *b*, the unburnt gases of the interior may be drawn off and inflamed at the other end of the tube.

123. The simple burning of a gas would not, however, account for the light it gives. The excessively feeble light of burning Hydrogen has already been noticed. It is scarcely visible in sun-light. And even the flame of **Oxy-hydrogen**, though possessing the greatest heat of all artificial flames, is in no degree more luminous.

Oxy-hydrogen is a mixture of Oxygen and Hydrogen in the proportions to form Water. As has been fully explained (par. 1), Water is a compound of Hydrogen and Oxygen. If then these two gases are mixed together in the proportion of two volumes of Hydrogen to one volume of Oxygen, we obtain Oxy-hydrogen. It is only on combustion that water, or hydrogen oxide, is formed. The flame is solid. When fired, Oxy-hydrogen detonates loudly; the water formed, issues as steam, which is instantly condensed, and its place supplied by air,—the collision of the particles of which occasions the noise. The introduction of any solid object, such as wood or platinum, into such a flame, immediately renders it luminous. One of the most brilliant lights known, the Lime-light, is obtained by introducing a piece of Lime into the feeble Oxy-hydrogen flame; when its rays of light are concentrated by a proper mirror the light has been visible at a distance of 112 miles.

124. The solid matter which gives **light** to the flame of a candle or of gas is **finely divided carbon.** The gases, consisting mainly of Light and Heavy carbonetted hydrogen, under the influence of heat are at first decomposed into Carbon and Hydrogen. In the portion of the flame where this takes place there is only enough Oxygen to burn the Hydrogen, which inflames on account of its greater attraction for Oxygen. The Hydrogen, in burning, forms water and gives out so much heat that the liberated **carbon,** instead of being deposited in the form of soot, is heated to whiteness, but does not burn until it reaches the very outermost part of the flame, where, finding a free supply of **oxygen,** it is converted into **carbonic acid.**

125. The presence of **free carbon,** in every light-giving flame, is easily shown by depressing a plate, or any other cold object, upon it; the Carbon is immediately deposited as lamp-black. It is often unpleasantly manifested by a smoky flame, and the deposit of soot upon the ceiling. A flame carried rapidly through the air always smokes, because the quick accession of air cools it below the point necessary for the complete combustion of its Carbon.

126. This, then, is the mechanism of flame. It may be seen by the eyes to consist of three parts. A quantity of undecomposed gas, ready to burn, forms the centre of the flame (*a*), as a dark cone, fig. 18; in the bright, or light-giving part, this gas is kindled and

decomposed, and the burning **hydrogen** ignites the particles of **carbon**; whilst in the outermost portion of the flame this Carbon itself burns, forming Carbonic acid, which, with the Water from the burnt Hydrogen, forms a thin atmosphere round and above the flame. The hottest part of the flame is near the top, where the combustion is complete, while the temperature in the centre is so low, that in a large flame gunpowder may be placed without being kindled.

127. The different characters of these three parts of flame may be well demonstrated by an experiment suggested by the late Professor Faraday. If a glass syphon (fig. 19), properly supported, so as not to burn the fingers, be held in the dark centre of the candle flame, a quantity of white vapour arises in the tube which may be collected in the tumbler and inflamed. If the syphon be held at the point of the flame, Water is collected, and a colourless gas, found to be Carbonic acid, and which extinguishes a lighted taper, fills the glass. Lastly, if the syphon be depressed into the light-giving portion of the flame, the tube and glass become filled with blacks (carbon).

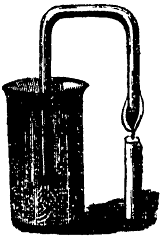

Fig. 19.

128. At the bottom of the flame, as well as at the outside, the gas is in perfect contact with the air, and here also complete combustion takes place, so that in this portion of gas-flame a colourless semi-circle may always be seen. If a plate be depressed into this part of flame, no soot is deposited on it. Advantage is taken of this fact in the various gas-burners employed for heating purposes. Fig. 20 represents a **Bunsen burner** so constructed, that the coal-gas mixes, in the tube, with the air which is admitted through small

holes near the base. The mixture burns with a pale flame, and with very slight luminosity, owing to the complete oxydation of the carbon at the same time as the hydrogen.

129. If the combustion is quickened by a jet of air, the heat of a flame may be considerably increased; upon this principle depends the action of the **blow-pipe.** A current of air is projected by means of the tube *a* along the surface of the wick (fig. 21), and the flame blown out of its vertical position into the form of a pointed cone, in which the three parts of the flame are distinctly visible. In the luminous part are enclosed the yet unburnt combustible gases, possessing such great affinity for Oxygen, as immediately to deprive of that element the Oxides of most metals that may be brought into them. Hence, this portion is called the **reducing** or **de-oxydizing flame,** because it removes the oxygen. At the summit of the flame, where it is fully oxydized, the opposite effect is produced, so that a metal, such as Tin, introduced into it, immediately becomes converted into

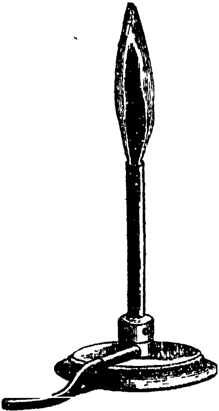

Fig. 20.

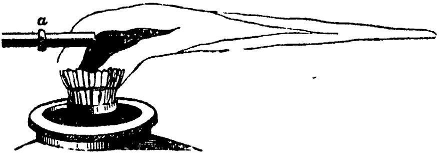

Fig. 21.

an oxide. This part of the flame is hence called the **oxydizing flame.**

130. It has been already stated (par. 95) that when a body is **burnt, it increases in weight** by just so much as the weight of the oxygen added to the burning body. The following experiment is derived from the late Dr. Miller's Inorganic Chemistry:—A glass tube *a b*, fig. 22, is divided at *o* by a diaphragm of wire gauze and the upper part filled with caustic potash *d*, which will retain the whole of the Carbonic acid and Water produced in the combustion of the taper *b*, placed on a perforated cork fitted to the lower end of the tube. The aspirator *A*, filled with water, is capable of closure by the stopcock *s*, its upper end being connected by the bent tube (likewise containing potash) *g h*, with the long vertical tube *a b*. Now as the water cannot escape from the open tap, unless communication is made with the outer air, on account of the upward pressure of the latter, and as the air can only enter through the holes in the cork upon which the taper is placed, it follows that when the tap is turned, a current of air is established through *b*, *c*, and the water flows. When all arrangements for the experiment are made, the tube is weighed, connected at *e e* by means of vulcanized india-rubber tubing with the aspirator, the taper lighted and the tap opened. The air at *b* supplies the taper with the Oxygen necessary for its combustion; and, if the tube be disengaged from the aspirator, and weighed after the taper has burnt out and the whole cooled down, it will be found to have increased several grains in weight.

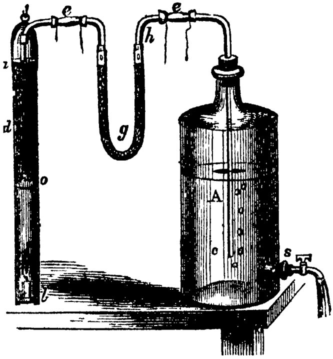

Fig. 22.

131. Flame requires a very high temperature for its existence, so that if it be cooled down below a certain point, it is extinguished. The deposit of **soot or carbon** from a flame, on a cold plate, or from a burning candle when wafted through the air, are illustrations of the effects of cooling. Admixture of Gas with a considerable excess of air beyond what is necessary to burn it, brings about the same result. If Light carbonetted hydrogen, the Firedamp of the coal-mines, is mixed with more than sixteen times its bulk of air, it can no longer be inflamed, and much less exploded, by reason of this cooling power possessed by so large a volume of air. Sir Humphry Davy found that a mixture of explosive gases could not be inflamed through a narrow

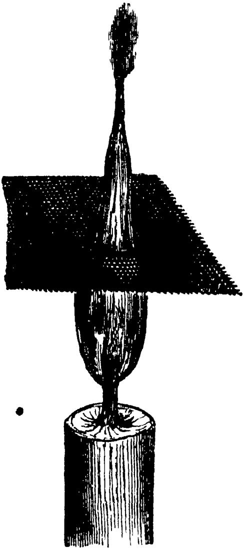

Fig 23.

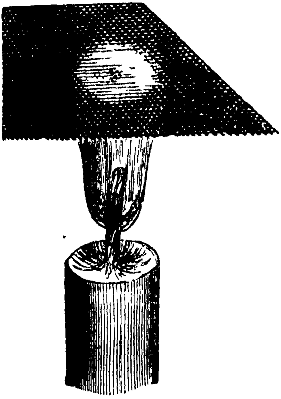

Fig. 24.

tube, owing to the cooling influence exerted by the tube on the flame. If wire-gauze with about 400 meshes to the square inch be depressed into the candle or gas flame, the upper part will be cut off (fig. 24), because the unburnt gas is reduced in temperature below the point of combustion. It may be kindled by the application of a light above the gauze (fig. 23), and the gas will then continue to burn both above and below. The experiment may be varied by turning on an unlighted jet of gas beneath the gauze; on the application of a light above the gauze the gas will inflame, but the cooling power of the gauze will prevent the flame from passing through.

132. This principle finds its most perfect and useful application in the **Davy Safety-lamp.** It consists of an oil-lamp (fig. 25) enclosed within a cylinder of wire-gauze. A small movable wire passing through a closely-fitting tube and bent at its upper end, reaches the wick, and can be used to trim it without removing the cage. When such a lamp is carried into a coal-mine containing an explosive gas, the flame is sometimes seen to fill the whole interior of the gauze. When that is the case, the miner has notice of danger and should at once withdraw; for, if the cage should become oxydized, as it would soon be at that high temperature, several meshes might break, so as to form a hole in the gauze, and an explosion would arise, fatal to the miner either from the flash of the flame, or by the deadly effects of the resulting Carbonic acid, or from both causes combined.

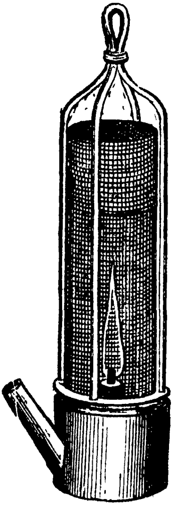

Fig. 25.
THE SAFETY LAMP.

The chief use of the Davy Lamp ought to be, to enable the viewer of the coal-mine to examine it carefully before the miners are allowed to enter the mine. An explosive atmosphere is of necessity unfit for respiration; so that good ventilation is the miner's only complete protection from danger to health or life.

133. The above principles find their application in the varieties of flame used for illumination. As the **light** depends on **Carbon** at a white heat, it follows that the richer a gas is in Carbon, the higher is its illuminating power. In Coal-gas this power depends principally upon the Heavy carbonetted Hydrogen, which contains just twice as much Carbon as the Light carbonetted Hydrogen.

134. The **degree of light** given out by a flame depends on the amount of air supplied to it. If it receives too little air, the combustion is incomplete, the flame smokes, and gives out only an imperfect light. If it receives too much, it is cooled down and again its light is diminished. Hence the best burner will be that which admits the air to the flame in just sufficient quantity to obtain the greatest light. By the Bat's-wing and Swallow-tail burners (in the former of which the Gas issues through a narrow slit, and in the latter through two slits), the flame is made as thin and wide as possible, so as to present a large surface to the air. These, accordingly, give considerable light for a small quantity of gas.

135. In the **Argand burner,** the air is made to pass through the interior of the flame, as well as round it. This flame, therefore, condensing a large surface into a small space, is the brightest and most economical. A chimney is required, partly to increase and direct the draught from below, and partly to regulate the relative supplies of air to the outside and inside of the flame. The best light is obtained when the flame is cylindrical; as large at the top as at the bottom.

136. The **length of flame** is also a point worthy of consideration. The most economical length of flame to burn, is about 4½ to 5 inches; in other words, a flame of this length gives most light, in proportion to the amount of Coal-gas it consumes.

137. Many persons object to the burning of Gas in inhabited rooms, and it does render the air impure more than any other artificial source of light. One volume of good Gas produces three volumes of Carbonic acid and a large supply of watery vapour. And all gas contains some Sulphur-compounds (par. 62), which, when burnt, still further contaminate the air by the Sulphurous acid which they contribute to it. These several impurities produce very injurious consequences to the health and comfort of many who breathe them. The deleterious effects of Gas-burning have been sometimes strikingly shown by the injury it has inflicted on articles in rooms, such as metal-ornaments, curtains, books, and so forth. These effects can only be remedied by perfect ventilation. But, if people would be contented with the same amount of light they were accustomed to in past days, when they burnt candles or oil, then the advantage of Gas, in price, becomes obvious; not only is much less heat, but less Carbonic acid produced.

138. The various **paraffin oils** so much used at the present day are also Hydro-carbons; that is to say, they are liquid compounds of Carbon and Hydrogen. By the use of a wick it is easy to accomplish their combustion, but not without a slight smell on account of their volatility. The gas produced is very similar in composition to ordinary Gas, but relatively richer in Heavy Carbonetted hydrogen. There is, however, a total absence of Sulphur-compounds. Some of the paraffin-oils are dangerous on account of their volatile character, producing with the atmosphere explosive mixtures; but this is not the case with any of those of established reputation, such as Young's, &c. One precaution should always be taken; never to trim the lamp near a light or a fire.

139. **Candles** are made by the processes of Dipping and Moulding. The former process consists in immersing the prepared wicks repeatedly in a bath of the melted material, until a sufficient quantity has adhered

to them, and in this case the candles are called "dips." In the latter process, the wicks are fixed in the centre of metallic moulds of the dimensions of the intended candles, into which the melted fat is poured. These are sold as "Mould candles."

140. **Wicks** are generally made of fine cotton threads, twisted, plaited, or otherwise turned. In a well-made wick there should be neither knots nor loose fibres, as their presence tends to produce the well-known phenomenon of guttering. This effect is caused by the extension of the flame beyond the cup-like hollow in the top of the candle which ordinarily holds the whole of the melted material, by which the outside edge of the candle is melted, and the grease allowed to run down. The finer the threads that form the wick, the more perfect is the absorption of the material of the candle and, consequently, the more brilliant the combustion. The action of the wick depends upon **capillary attraction,** a term intended to express the adhesive force exerted by the sides of vessels upon liquids contained within them, by which they rise in tubes of narrow bore to a considerable height above the surface of the fluid in which the tubes are placed. Since adhesion is a surface-power, the more nearly the sides of the tube approach, the higher will be the level to which the liquid rises. The word "capillary" is derived from the Latin word Capillus, a hair, because the finer and more hair-like the tube, the higher will be the ascent of the liquid in which it stands. Though the fibres of the wick are not themselves actual tubes, yet the spaces between the fibres have precisely the same action, the melted material of the candle being drawn by capillary attraction to the top of the wick, where it is inflamed. In finer wicks the ascent of the liquid is higher, and the flame being further removed from the candle, a smaller portion becomes melted by it; the combustion, too, being slower and therefore more complete, the candle burns longer.

141. In chemical composition most **wicks** have the same character as dry **wood**, and require for complete

combustion more Oxygen than they can obtain in their position in the centre of the flame ; and as, for want of it, the whole of their Carbon cannot be consumed, they need occasional snuffing. With a view to the removal of this incomplete combustion of the wick, which not only requires the use of snuffers, but interferes materially with the uniformity in the light of the flame, some wicks are so placed as to untwist in burning, and to bring their ends into the outer flame where they find the air necessary for their complete combustion.

142. The commonest kind of candles are made from **tallow**, melted down and freed from its natural impurities. When fresh it has but little smell, and melts at about 38°C. Unlike most sources of artificial heat and light, it is of animal origin, but it only contains the same elements, Carbon, Hydrogen, and Oxygen, and yields similar gases to those with which we are already familiar. Tallow contains about 75 per cent. of a hard, lustrous fat, which is called **stearin**, a compound of **stearic acid** with **glycerin.** When the glycerin is removed, stearic acid remains, a substance which can be made to yield candles of a very superior description, as the melting-point is so much higher than that of tallow.

142. But the most important substance used in candle-making is Palm-oil, the fruit of a tree which grows on the coast of New Guinea. The Palm-oil of commerce contains about 30 per cent. of a solid fat which is known by the name of **palmitin.** Like most of the materials employed in making common candles, palmitin melts at too low a temperature to be generally serviceable. It is a compound of **palmitic acid** with **glycerin** : when separated from the glycerin with which it is combined, palmitic acid presents the appearance of a perfectly white substance, of considerable hardness, and of great value.

143. **Paraffin** may be considered as solid Gas. It is a compound of Carbon and Hydrogen in the same proportions as in heavy carbonetted hydrogen. It is

obtained in very considerable quantities from Boghead and Leeswood cannel coals, by a species of destructive distillation. When burnt, the results are the same as those from Light and Heavy Carbonetted Hydrogen; the Carbon burns to Carbonic acid, and the Hydrogen to water.

144. The **wax** used for making candles is derived entirely from bees. As collected from the honeycomb, wax is of various shades of colour. It is melted in hot water and drawn out into the thinnest possible sheets, which are exposed to the bleaching action of the air, light, and moisture. Its constituents are only Carbon, Hydrogen, and Oxygen, and the results of its combustion in air, only carbonic acid and water.

CHAPTER VI.

ON THE CHEMISTRY OF THE FOUR ELEMENTS, HYDROGEN, OXYGEN, CARBON, AND NITROGEN, AND OF THEIR COMPOUNDS.

144. We have seen that the air contains four elements. **Oxygen** and **Nitrogen** in a **free state**; **Carbon**, in the form of oxydized carbon, or **Carbonic acid**; **Hydrogen**, in the condition of oxydized hydrogen, or **water**, and of **Ammonia**, a compound of **Nitrogen** with **Hydrogen**. And we have learnt that every compound containing carbon and hydrogen, when fully burnt, yields carbonic acid, and water. It is therefore necessary that we should know somewhat more accurately, what are the properties of these elements which are of such universal occurrence.

145. **Hydrogen** is a colourless gas, tasteless and odourless when pure, and scarcely ever found in the free state or "native." Cavendish discovered it in 1766, and he prepared it from **water**, the **oxide** of

hydrogen. It is an element, the lightest of all the elements, and is sometimes used for filling balloons. It derives its name from its leading character; it comes from the Greek words signifying the formation of water. When heated in air Hydrogen inflames, burns at the expense of the oxygen, and forms water. [Hydrogen is shortly expressed by the letter *H.*] Hydrogen is most readily prepared from its **oxide, water.** If water be boiled in the retort *a*, fig. 26, and its steam passed over iron filings contained in the gun barrel *b*, and made red-hot by glowing charcoal, Hydrogen passes over, and may be collected in the tube *c*, inverted over water. Iron is an element: at a red-heat its affinity or attraction for oxygen is greater than that of the hydrogen for oxygen, and so an oxide of iron is formed, and Hydrogen is set free.

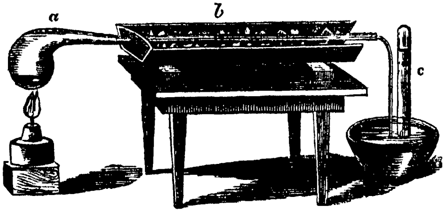

Fig. 26.

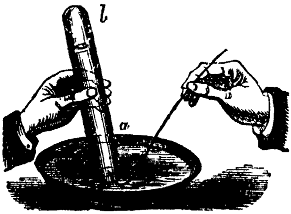

Fig. 27.

Hydrogen has many of the properties of a **metal.** Most metals drive hydrogen out of its combination with oxygen, water. The metals Potassium and Sodium do so at any temperature. The mode of proceeding with sodium is illustrated in fig. 27. A piece of **Sodium,** as big as a small pea, is fastened to the wire held in the hand; when carefully, but quickly, introduced under water, the Sodium detaches itself, and rises, owing to its lightness, to the surface of the water contained in the wide test-tube *b*. The Hydrogen is set free and speedily fills the tube; the Sodium takes its place in the water. [Instead of hydrogen oxide we have Sodium oxide, which dissolves in the excess of water as Sodium hydrate.]

Hydrogen is much more commonly prepared from water, with the aid of zinc and hydrogen sulphate. The arrangement is seen in fig. 28. The zinc being placed at the bottom of the Wolffe's bottle *b*, and covered with water to the extent of two inches, Hydrogen sulphate is carefully poured down the thistle-funnel *a*. [The zinc drives out the hydrogen, which may be collected over water; zinc sulphate is found in solution in the water.]

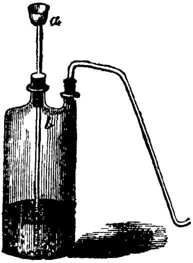

Fig. 28.

146. **Oxygen** is a colourless, tasteless, and inodorous gas. It is a great supporter of combustion (par. 93), but does not inflame. As already shown, it is required and removed from the air in respiration (par. 44), decay (par. 46), and germination (par. 45).

In water Oxygen is somewhat more soluble than Hydrogen: but it is only soluble to the extent of three measures in one hundred measures of water. It is sixteen times heavier than the same measure of Hydrogen.

The name Oxygen was given from two Greek words which signify " acid making," as many of the elements burn in oxygen and form acids. This is the case with Sulphur, Phosphorus, Boron, Carbon, Silicon, Antimony, and Arsenic.

Oxygen occurs both in the free state and in combination; indeed it is the most abundant of all the elements. In the atmosphere, mixed with nitrogen, 21 per cent. of oxygen is met with. No less than eight parts out of nine ($\frac{8}{9}$) by weight of water consist of oxygen, but in a state of **combination.** It is a component of nearly all minerals; so completely are these latter oxydized that they cannot be burnt any more. Lastly, oxygen is contained in all vegetable and animal matters.

Although so abundant, Oxygen is difficult to obtain from the air. This is owing to its powerful affinities: it will scarcely leave anything alone, except of course oxydized bodies. It is sufficiently easy to withdraw it from the air (par. 26), but then it enters into combination with something else.

Any of the **oxides** of the noble metals **Gold, Silver, Platinum,** and **Mercury,** might however be employed to make oxygen. The least expensive is **mercuric oxide.** When this is strongly heated in a tube of hard German glass, it breaks up into mercury and oxygen.

Certain other oxides, called **peroxides,** may also be employed: they do not part with the whole of their oxygen, but are brought down by heat to lower oxides, or such as contain less oxygen. **Manganese peroxide** is most commonly used.

But **Potassium chlorate** yields **oxygen** most readily. It is a salt consisting of Potassium, Oxygen, and Chlorine. When heated, it melts, and at a higher temperature loses the whole of its oxygen: **Potassium chloride** remains.

The gas is collected in the pneumatic trough (fig. 29). The arrangement for making Oxygen from a test-tube, will be understood from the illustration without further explanation. A mixture of potassium chlorate with manganese peroxide, is better than the potassium chlorate by itself, as less heat is required.

It has been already stated that oxygen is possessed of very powerful attractions for other elements, and, as a natural consequence, there are many varieties of oxydized bodies.

[The **first letter** of the word is employed by chemists to denote each element, except when two have the same initial letter; then a **second letter** is added. So, then, *O* stands for Oxygen, and *H* stands for

Hydrogen. And not simply for Oxygen and Hydrogen, but for a given weight of these elements.]

147. **Carbon** in its purest form is known as the **Diamond.** This highly-prized gem, as found, presents the appearance of a rounded pebble, enclosed in a thin, opaque crust. Freed from this coating it is generally colourless. It crystallizes in regular forms, and is the hardest known body. When very strongly heated in absence of air, it becomes transformed into a substance like Coke.

Carbon also occurs as **graphite** or **plumbago.** In this form it has a lustrous appearance, and readily leaves a mark upon paper, or the finger. It is quite unaffected by exposure to air, hence its use in "black-leading" iron.

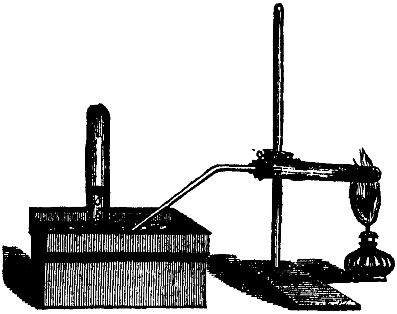

Fig. 29.

A third variety of Carbon is **lamp-black.** It was formerly obtained by collecting the smoke or soot of ill-trimmed lamps: hence the name. Its chief use is in the manufacture of printers' ink. **Charcoal** belongs to this third form of Carbon. It is a black, brittle, infusible substance, of well-known appearance. As it undergoes no change from exposure to air or moisture, it is a frequent custom to char the ends of posts and piles, with a view to their preservation. Thus, most of the houses in Venice are built on piles, all of which are deeply charred, and they have thus been able to resist the influence of centuries of exposure.

Every variety of Carbon, when heated in air or Oxygen, changes its solid condition, and becomes converted into invisible Carbonic acid. [The initial letter *C* is shorthand for Carbon.]

148. **Nitrogen** is a colourless, tasteless, and inodorous gas. It is not inflammable, neither does it support combustion. It is very little soluble in water. Nitrogen occurs in the uncombined state in the atmosphere; therein it amounts to 79 per cent. after the removal of the watery vapour. It is readily obtained, as it remains after the removal of the oxygen from air by means of burning Phosphorus (par. 26).

Like Oxygen, Hydrogen, and Carbon, Nitrogen is an element. [The initial letter *N* represents Nitrogen, and also the smallest quantity that can enter into combination. Comparing equal measures of Hydrogen, Oxygen, and Nitrogen at the same temperature, Nitrogen is 14 times, and Oxygen 16 times, as heavy as Hydrogen.]

149. The elements combine with one another in **fixed proportions** by **weight.** The smallest quantity of an element that can enter into union with another is called its **atom.** By the word we mean something that cannot be further divided, and the idea it also conveys is of something very, very small. Although the atoms of Hydrogen, Nitrogen, Oxygen, and Carbon cannot be further subdivided, yet are they possessed of definite weight. The symbol for Hydrogen is *H*; its combining weight is 1, as it is the lightest of all bodies, and is accepted as the **standard of comparison of combining weights** or **atomic weights.**

Hydrogen,	**H = 1**	**Nitrogen,**	**N = 14**
Oxygen,	**O = 16**	**Carbon,**	**C = 12**

150. **Water** is a compound of **Hydrogen** and **Oxygen** in fixed proportions by weight. In eighteen parts by weight of water, sixteen parts of Oxygen are united to

two parts of Hydrogen. [The symbol H_2O expresses the fact in shorthand.]

Water is a true oxide. When **Hydrogen** is inflamed in air, it burns to **hydrogen oxide** (par. 145), or **water.** The composition of water may indeed be at once determined. If the two poles of a galvanic battery, terminating in platinum ends, be plunged into water (acidulated with about $\frac{1}{8}$ of Hydrogen sulphate, so as to make it a better conductor of electricity), bubbles of gas are seen to arise at each pole or wire. If these gases are collected by placing tubes filled with the same acidulated water (fig. 30) on the terminals of each pole, twice as much gas will be found in one tube as in the other. At the positive pole, Oxygen is collected; at the negative, Hydrogen; the latter is double in quantity to the former. This experiment proves that water is a compound of two volumes of Hydrogen with one volume of Oxygen.

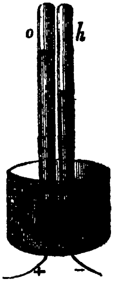

Fig. 30.

151. **Carbonic acid** is a compound of Carbon with Oxygen. It is a colourless gas, of somewhat acidulous taste and odour. Not only does it not support combustion, but it furnishes one of the simplest means of extinguishing flame. A lighted taper is immediately put out by it.

The choke-damp of the coal-mine, after an explosion of fire-damp, is carbonic acid. It is irrespirable.

When shaken with lime-water, **carbonic acid** forms a white compound called **Calcium carbonate**, or carbonate of lime; lime-water is therefore said to be a test for carbonic acid.

The gas is so heavy that it may be poured like water from one vessel to another (fig. 31). For the same reason it may be collected by displacing air, as it is half again as heavy as the air.

Owing to its weight, Carbonic acid is liable to collect at the place of its formation. Thus: in fermentation, at the bottom of the vats when the beer is drawn; in unused wells in which decaying leaves may be found; in coal mines after an explosion, &c. Care should be taken to explore such places before an attempt is made at cleansing, and this is easily done by the proper use of a light. It may be safely concluded that where a candle will not burn brightly, a man cannot live.

In water, Carbonic acid is very soluble, especially if the pressure be increased. One measure of water dissolves one measure of the gas, and this quantity increases regularly for each additional atmosphere. By a pressure of two atmospheres (twice fifteen pounds, par. 76), water can be made to dissolve twice its measure of carbonic acid. Under a pressure of 36 atmospheres, carbonic acid is compressed into a liquid.

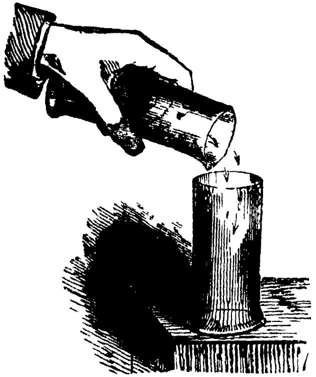

Fig 31.

Carbonic acid may be **prepared** by burning charcoal in oxygen. The experiment is a beautiful one, if a piece of charcoal made from the bark of a tree is employed. Of course the charcoal must be first ignited. Every substance containing carbon, when fully burnt in air, or in oxygen, is changed into carbonic acid, and therefore coal, and coal-gas, and candles, and lamps, in their burning, produce it largely.

But the most easy method is by the action of acids upon carbonates—the salts of carbonic acid. When marble, Calcium carbonate, is placed in a Wolffe's bottle (fig. 28, par. 145), and Hydrogen chloride (par. 172) poured upon it through the thistle-funnel *b*, Carbonic acid is driven out with effervescence, and may be collected in the pneumatic trough over water.

Salts of Carbonic acid are called **carbonates.** Washing soda is SODIUM CARBONATE. Pearl-ash is POTASSIUM CARBONATE. Chalk, Limestone, Marble, and Shells, are varieties of CALCIUM CARBONATE. White lead is LEAD CARBONATE. Malachite is COPPER CARBONATE.

[Carbonic acid is a compound of one atom of carbon with two atoms of oxygen. As **Carbon** is represented by the initial letter *C*, and **Oxygen** by the letter *O*, the symbol for **Carbonic acid** is CO_2. Twelve parts by weight of carbon (one atom), unite with 32 parts by weight of oxygen (2 atoms), to form 44 parts by weight of Carbonic acid.]

152. **Carbonic oxide** is also a gas, colourless, tasteless, and inodorous. It contains less oxygen than carbonic acid, and may therefore be inflamed. When lighted, it burns with blue flame, and the oxygen of the air which is necessary to its burning changes it into carbonic acid. It is easily formed when carbonic acid is made to pass over red-hot coal or charcoal; it is often thus produced, and then is seen burning with blue flame at the back of the fire.

[**Carbonic oxide is a** compound of one atom of carbon with one atom of oxygen; 12 parts of carbon are united to 16 parts of oxygen. Its symbol is *CO*.]

153. Carbonic acid and Carbonic oxide are both irrespirable; the latter is, however, much more injurious than the former. Nothing but good ventilation can do away with the injurious effects of carbonic acid, when produced in combustion, or in respiration.

154. **Light carbonetted hydrogen** (par. 115) is largely present in coal-gas. It may be described as a colourless, tasteless, and inodorous gas. When heated strongly in air, it burns with yellowish-white flame. As it is a compound of carbon and hydrogen, it burns in air into carbonic acid and water.

[It is a compound of one atom of carbon with four atoms of hydrogen. Its symbol is therefore CH_4.]

155. **Heavy carbonetted hydrogen** (par. 116), is also a colourless, tasteless, and odourless gas, burning,

when heated in air, with white flame to carbonic acid and water. It is more luminous than the former compound, as it contains twice as much carbon, and it is this which is the chief cause of the light of flames (par. 133).

This gas is an important constituent of all flames. It is also called olefiant gas and ethylene. [It is composed solely of carbon and hydrogen, and indeed of two atoms of carbon, to four atoms of hydrogen. Symbol C_2H_4.]

156. **Ammonia** (par. 55), is a compound of **nitrogen** and **hydrogen.** It is a colourless gas of pungent taste, and with smell as of "Hartshorn." When pure it is quite irrespirable ; diluted with air, it acts as a stimulant. It does not support combustion, but is itself somewhat inflammable, burning with very pale yellow flame into water and nitrogen.

Ammonia blues red litmus paper, and possesses an **alkaline** reaction. The word alkaline was the name given to Potash, to denote that it constituted the essence of the plant which yielded it. The word is derived from the Arabic article *al*, "the," and *kali*, the name of the plant. A body has an alkaline reaction when it turns red litmus blue.

The solubility of ammonia in water is remarkable. One measure of water at 15° C. dissolves 727 measures of the gas. Such a solution is generally sold, and the gas may be easily prepared by heating the solution in a flask. As ammonia is lighter than air, it can be collected in a wide test-tube, by simply holding it over the neck of the flask.

The chief supplies of ammonia are obtained from the distillation of coal. Gas liquor contains it. The name was given to it by the Romans, who found Sal-ammoniac in Ammonia, a district of Lybia, in Africa, where an Egyptian god, Amun, was worshipped. Ammonium carbonate is the common smelling-salts of the shops.

[The exact composition of Ammonia may be inferred from its symbol NH_3. It is a compound of one atom of nitrogen, with three atoms of hydrogen. The hydrogen can alone burn.]

157. **Hydrogen nitrate** is also called nitric acid. It is a strong, fuming, volatile, corrosive liquid; very poisonous and stains the skin yellow. It becomes yellow in the sunlight, and gives off ruddy fumes. Even when largely mixed with water, it reddens blue litmus paper, so that it possesses opposite properties to ammonia.

Hydrogen nitrate is made from certain **nitrates.** POTASSIUM NITRATE is saltpetre, so much used in making gunpowder. BARIUM NITRATE is employed in making Green-fire, and STRONTIUM NITRATE in making Red-fire.

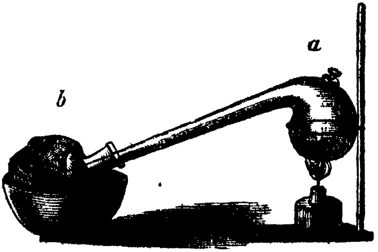

Fig. 32.

Equal weights of potassium nitrate and of hydrogen sulphate are employed in the manufacture of hydrogen nitrate. The distillation may be conducted as in fig. 32. The retort *a* is connected with the receiver *b*, the former is heated by a spirit-lamp, and the latter is cooled down by a rag soaking in cold water contained in a basin.

[In mixing hydrogen sulphate (par. 163) with potassium nitrate, the potassium changes place with the hydrogen; we therefore obtain potassium sulphate instead of hydrogen sulphate, and hydrogen nitrate instead of potassium nitrate. Hydrogen nitrate is a compound of **hydrogen, nitrogen** and **oxygen**; its symbol is HNO_3. AMMONIUM NITRATE is much used in making nitrous oxide or laughing gas. When heated, this salt breaks up into **water** H_2O, and **nitrous oxide** N_2O.]

CHAPTER VII.

THE CHEMISTRY OF THE ELEMENTS SULPHUR AND PHOSPHORUS, WITH A FEW WORDS ABOUT LUCIFER-MATCHES.

158. If the facts mentioned in preceding chapters have conveyed any meaning at all, they must have taught that all compounds are made up of fixed weights of various elements. The symbols for hydrogen, oxygen, nitrogen, and carbon always signify a fixed weight.

Chemists can construct **Tables of the combining weights** of the different elements, together with their symbols. This, including the elements Sulphur and Phosphorus, we can illustrate by the following Table :—

Hydrogen, H = 1
Nitrogen, N = 14
Oxygen, O = 16
Carbon, C = 12
Phosphorus, P = 31
Sulphur, S = 32

159. **Sulphur** is an element; a solid of a pale-yellow colour. It is met with in the uncombined state, or "native," in the blue clay of Sicily, as well as generally on the coasts of the Mediterranean. It is sometimes found in transparent, yellow crystals of considerable size. When mixed with clay, the sulphur is easily separated by the aid of heat, inasmuch as it is volatile, and may be sublimed in absence of air.

In commerce Sulphur is known as Brimstone, and as Roll sulphur. Also as Flowers of Sulphur, so much used in medicine.

When sulphur is melted, the amber-coloured liquid which is first formed, deepens, and changes from brown to a rich treacle colour. From being so thin a fluid that the sulphur may be poured out like water, as is the case at first, at a higher temperature it becomes so tenacious, that the containing vessel may be turned upside down without any loss of liquid! If now the sulphur be further heated to its boiling point (440° C.), and then suddenly cooled by pouring it into water, it is found to be plastic and may be cast into moulds, or pulled into threads. If further heated, but still in absence of air, the sulphur volatilizes, and the vapour condenses into "Flowers of Sulphur."

Sulphur melts at 150°. It is insoluble in water, but soluble in carbonic sulphide (par. 164). If heated either in air, or in oxygen, it **oxydizes**, and becomes converted into a gas possessed of most suffocating properties: this gas is called **Sulphurous acid**, and great care should be taken not to breathe it.

Many combinations of sulphur are met with in nature. One of its compounds, **Hydrogen sulphide**, is a very common emanation from sewers, and from all decomposing animal matters containing sulphur and hydrogen. Many **other metals**, besides hydrogen, occur as **sulphides.** Lead sulphide is the common ore of lead called Galena; Zinc sulphide is Blende; Copper and Iron sulphide is Copper-pyrites; Iron-pyrites is Iron sulphide; Silver sulphide is known as Silver-glance; Quicksilver sulphide, as Cinnabar or Vermilion.

160. As a rule, when a **sulphide** is strongly **heated in air**, both the **metal** and the **sulphur oxydize**; the sulphur volatilizes in the form of sulphurous acid gas (par. 162), and the metal remains in the oxydized form.

[The symbol for sulphur is *S;* its combining or atomic weight is 32.]

161. **Hydrogen sulphide**, or sulphuretted hydrogen (par. 63), is a compound of hydrogen and sulphur. It is a colourless gas, of most offensive odour, as of putrid eggs. It is irrespirable and poisonous. Water dissolves three volumes or measures of the gas and acquires all its properties. Harrogate and other hepatic waters contain it in solution. In the air it may be kindled and burns, with blue flame, into sulphurous acid and water. The best antidote is Chlorine, because the latter immediately decomposes it.

The test for even minute quantities is *lead-paper*, or filtering-paper soaked in a solution of sugar of lead; by the formation of lead sulphide, which is black, the presence of the gas is known. [Symbol H_2S.]

162. **Sulphurous acid**, a compound of sulphur and oxygen, has been often mentioned. It is a colourless gas, pungent and suffocating, reminding of its origin —burning brimstone. Water dissolves 69 times its volume at 0° C. Its solution reddens litmus, and bleaches flowers. The gas is much employed in bleaching straw and flannel; as a disinfectant; in the preservation of meat and fish, and in the prevention of fermentation.

Sulphurous acid is readily prepared by burning sulphur in air or in oxygen, or by heating metallic sulphides strongly in air. [The chemical symbol for **Sulphurous acid** SO_2, at once tells its composition.]

163. **Hydrogen sulphate** (**Sulphuric acid**, or **Oil of vitriol**) is the most important, and generally the most powerful, of all salts of hydrogen. It is a dense, oil-like liquid. It is much heavier than water; more than four-fifths; its relative weight is 1·84. The liquid boils at 338° C. and distils. Most organic substances char or blacken when introduced into hydrogen sulphate; this is owing to its affinity for water. When added to water, great heat results, and the mixing requires caution.

A pretty experiment may be performed, in a dish, by moistening a small quantity of lump-sugar with boiling water, and pouring hydrogen sulphate upon it. The sugar, which consists of carbon and the elements of water, is changed by the acid into black carbon, and into water.

Even a drop of hydrogen sulphate in a pint of water will redden litmus paper. When added to a nitrate, hydrogen nitrate (par. 157) is set free; to a carbonate, carbonic acid (par. 151). Diluted hydrogen sulphate is employed in making Hydrogen (par. 145); the zinc takes the place of the hydrogen, and forms zinc sulphate.

There are many **Sulphates** in common use. Green vitriol is Iron sulphate; blue vitriol is Copper sulphate; white vitriol is Zinc sulphate; Epsom salts is Magnesium sulphate. Alabaster and Selenite are Calcium sulphate, or lime sulphate.

The **manufacture** of oil of vitriol is conducted in leaden chambers. Sulphurous acid is supplied from either burning sulphur, or iron-pyrites (iron di-sulphide). When nitrous acid comes together with sulphurous acid, the latter takes oxygen from the former, and dissolves in presence of water as hydrogen sulphate. [**Hydrogen sulphate,** H_2SO_4, contains two atoms of hydrogen, one atom of sulphur, and four atoms of oxygen. Its combining weight is therefore said to be 98, made up of 2 atoms of hydrogen = 2; one atom of sulphur, 32, and 4 atoms of oxygen, 4 times 16 = 64.]

164. **Carbonic sulphide** is a compound of carbon and sulphur. It is a liquid with the odour of cabbage-water, and so volatile that it evaporates at common temperatures. Sulphur and Phosphorus dissolve in it readily; its chief employment is as a solvent of india-rubber.

At a red heat Carbon and Sulphur unite to form carbonic sulphide. The operation is of course conducted in the absence of air, as the compound readily inflames, and burns to carbonic and sulphurous acids.

[Carbonic sulphide is a compound of one atom of carbon with two atoms of sulphur. Symbol CS_2.]

165. **Phosphorus** is an element which was discovered by Brandt in 1669. The name is derived from the Greek words signifying "light-carrier," expressing one of the properties of phosphorus, viz., its luminosity in the dark. Phosphorus is never found native, but in an oxydized form it is an abundant constituent of bones, and, in smaller quantities, of all vegetables and animals, and of all fertile soils.

Phosphorus is a pale, wax-like, lustrous solid, very nearly twice as heavy as water, in which liquid it is insoluble. Its melting-point is so low (44° C.), that it requires great care in handling, for the moment of melting in the air is also the moment of inflammation. For purposes of *experiment* it should always be *cut under water.*

Common phosphorus is so inflammable that it must be kept under water. It is generally sold in sticks, which are easily cast in moulds under warm water.

Phosphorus is very poisonous. The burns which it inflicts are most dangerous.

The changes which phosphorus undergoes when exposed to light, or when heated in absence of air, are very remarkable. The most important variety is the **red phosphorus**, which is made by heating common phosphorus for several days, in total absence of air, at a temperature of about 250°. When thus prepared it forms a red powder, insoluble in all liquids, free from poisonous properties, and only inflammable in air at a high temperature.

The solubility of phosphorus in carbonic sulphide affords a ready means of separating common from red phosphorus: such a solution, when poured upon blotting-paper, leaves a film of phosphorus which inflames spontaneously in the air.

166. Phosphorus forms a compound with hydrogen, called **Hydrogen phosphide**, which, in composition [PH_3], and in properties, closely resembles ammonia, the place of the nitrogen being taken by phosphorus. It is however insoluble in water and very inflammable, and burns to water and phosphoric acid.

Hydrogen phosphide has the smell of putrid fish. It is prepared by boiling Phosphorus in a solution of caustic potash (fig. 33). At the same time a very small quantity of a liquid is produced which renders the gas spontaneously inflammable. The appearance is most beautiful from the formation of ever-widening rings of snow-white phosphoric acid.

167. When Phosphorus is heated in air, it burns with beautiful white light into **Phosphoric acid.** This substance is a snow-white powder, possessing the

most greedy attraction for water, so that in the air it rapidly flows into a liquid. When once united with water, even a white heat fails to separate it. Thus it may be melted, and then presents the appearance of ice, and is known as glacial phosphoric acid. [Chemists call it **hydrogen metaphosphate.** In composition it resembles **hydrogen nitrate** HNO_3.]

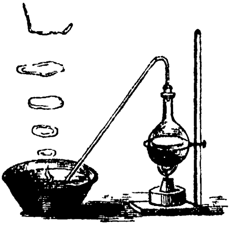

Fig 33.

[There are several hydrogen phosphates. Glacial phosphoric acid is known as **Hydrogen metaphosphate** HPO_3. Common hydrogen phosphate is the **Orthophosphoric acid** H_3PO_4, of chemists. When a bone is burnt, the white ash which remains is **Calcium ortho-phosphate,** and from it Phosphorus is prepared (par. 272).]

Phosphorus is so inflammable that we have already employed it for removing oxygen from the air (par. 26). At a white heat carbon will take the oxygen from phosphoric acid, and thus we may **prepare** phosphorus.

168. The chief use of phosphorus is in the manufacture of **lucifer-matches.** Some forty years since, the tinder-box with flint and steel to obtain a spark, and the brimstone-match to obtain a flame, were in request in every household. The discovery that phosphorus would inflame upon slight friction, and so inflamed would kindle a brimstone match, soon put an end to the use of tinder. In the commonest lucifers, the wood is dashed over at the end with sulphur, and plunged into a mixture containing phosphorus and potassium chlorate. The phosphorus is generally made up into an emulsion with gum, and subsequently mixed with the potassium chlorate: the oxygen of the latter inflames the phosphorus when the match is

moved by friction over sand-paper. Other inflammable materials, such as paraffin (par. 148), may be substituted for the sulphur, and thus one disagreeable element removed from the match. But the most serious evil connected with the manufacture of matches is the injury to the health of those employed, arising from the vapours of the common phosphorus. This is entirely prevented by the use of Bryant and May's Safety Matches, in which the red phosphorus is employed. The brown deposit on the sides of the box contains the red phosphorus; the match is only tipped with potassium chlorate or some other substance which supplies the necessary oxygen. Not until the match is rubbed upon the phosphorized surface can it be kindled! In this way, too, many fires are prevented which arise from the careless use of the common match.

CHAPTER VIII.

THE ELEMENTS CHLORINE, BROMINE, IODINE, AND FLUORINE, CONSIDERED IN RELATION TO ONE ANOTHER AND TO HYDROGEN.

169. The elements **chlorine, bromine, iodine, and fluorine** are never found native, but always in combination with certain metals. These are the salts called **chlorides, bromides, iodides,** and **fluorides.** Common salt, or SODIUM CHLORIDE, is perhaps the best known.

[If we add these elements to those already named, the Table given in the former Chapter may be considerably extended. The names, symbols, and atomic weights would be as follows:—

1. **Hydrogen**, H = 1
2. **Nitrogen**, N = 14
3. **Oxygen**, O = 16
4. **Chlorine**, Cl = 35·5
5. **Fluorine**, F = 19
6. **Bromine**, Br = 80
7. **Carbon**, C = 12
8. **Iodine**, I = 127
9. **Sulphur**, S = 32
10. **Phosphorus**, P = 31

The first five elements are gases. Bromine is a liquid. The other four elements are solids.

Bromine and Iodine can by heat be easily changed into vapour, and so also, but not easily, can Sulphur. The combining weights of these elements also represent their relative weights. Thus, Chlorine is 35$\frac{1}{2}$ times heavier than Hydrogen, and the smallest amount of Chlorine, that can enter into combination, is 35$\frac{1}{2}$ times as heavy as the smallest amount of Hydrogen.

Carbon has never been volatilized. Phosphorus has this peculiarity, that one volume of its vapour is sixty-two times as heavy as the same volume of Hydrogen; there are two atoms of Phosphorus in one volume.]

170. **Chlorine**, so well-known for its bleaching and disinfecting properties, is a gas of yellowish-green colour. The name, in Greek, signifies yellowish-green. Utterly irrespirable and suffocating as it is, Chlorine can only be breathed in admixture with a large volume of air. Water dissolves twice its volume of the gas, and the solution acquires the colour and the properties of Chlorine. When the water is at the freezing-point, Chlorine unites with it to form a crystalline solid.

The affinity of **Chlorine** for **hydrogen** is so great that it will decompose water, or hydrogen oxide, in presence of sunlight; the result being hydrogen chloride, and oxygen. Because the flame of a candle contains hydrogen in the form of carbonetted hydrogen (par. 138), and because of this affinity of Chlorine for Hydrogen, a candle burns in Chlorine with a reddish sooty flame. Turpentine, which is a compound of Carbon and Hydrogen, bursts into flame when introduced into chlorine; the latter unites with the hydrogen to form hydrogen chloride, and deposits the carbon with which it is united in the form of soot. Heavy carbonetted hydrogen (par. 155) when mixed with twice its volume of

Chlorine, burns on the application of a light with a beautiful white flame, and with a heavy deposit of carbon in the form of soot. All which goes to prove, that chlorine, at common temperatures, has no affinity for carbon.

Many of the heavy metals take fire when plunged into chlorine. Dutch leaf, pounded antimony, and arsenicum, at once form **chlorides** of the respective metals.

Every **metal** has its **chloride**; nearly all chlorides are soluble in water. The two exceptions are: SILVER and MERCUROUS CHLORIDE. The latter is also called calomel.

Chlorine is a great **bleaching** and **disinfecting** agent. This is quite intelligible. The most injurious gases, as hydrogen sulphide (par. 161), and hydrogen phosphide (par. 166) are instantly decomposed by chlorine; hydrogen chloride is formed, and either sulphur, or phosphorus, deposited. In sunlight, chlorine decomposes water; a portion, at least, of the oxygen is separated with the valuable properties of ozone (par. 60). In cases of bleaching, chlorine removes hydrogen from the coloured compounds, and thus destroys them.

Chlorine is most readily **prepared** from its compound with **hydrogen.** Hydrogen chloride is heated in a flask, fig. 34, with manganese peroxide. Owing to its weight (2½ times heavier than air, and 35½ times heavier than hydrogen), Chlorine may be collected by displacing the air; the bottle is known to be full by the yellowish-green colour of the gas.

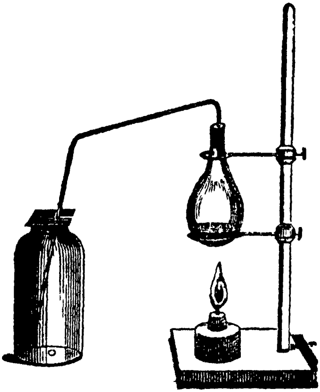

Fig. 34.

171. [The symbol for Chlorine is Cl. The second letter l is added, to distinguish it from Carbon. Its combining, or atomic weight is 35·5. When **hydrogen chloride** HCl, is heated with **Manganese peroxide** MnO_2, the hydrogen unites with the oxygen to form **water** H_2O; at the same time, one portion of the chlorine unites with the metal manganesium, to form **manganous chloride** $MnCl_2$, and the other portion of **Chlorine** is set free. Now, as the elements unite in fixed proportions by weight, it is not only possible always to obtain the same amount of chlorine, but to express the quantities in symbols. Here is an illustration of a chemical equation expressed in symbols.

$$4\ HCl + MnO_2 = MnCl_2 + 2\ H_2O + Cl_2.$$

That is to say 4 atoms of hydrogen chloride, and one atom of manganese peroxide, would yield one atom of manganous chloride, two atoms of water, and two atoms of chlorine.]

172. **Hydrogen chloride** is the only compound which hydrogen forms with chlorine. It is a colourless gas, irrespirable, uninflammable, and possessed of all the properties common to acids. It fumes in air and is very easily soluble in water. At the freezing-point, water dissolves 500 times its own measure of the gas. This solution is often called hydrochloric, or muriatic acid; the latter is yellow from the presence of iron chloride. The gas, as well as its solution, reddens litmus. When hydrogen chloride is brought together with ammonia, white fumes of **Ammonium chloride** or sal-ammoniac are formed.

Hydrogen chloride is not only used for making Chlorine, but also for making Carbonic acid.

Upon a small scale the gas may be made by mixing together equal measures of hydrogen and chlorine, and detonating the mixture by flame. For laboratory purposes it may be prepared in solution in water, by distilling sodium chloride with hydrogen sulphate, and collecting the gas in pure distilled water. [The hydrogen of the hydrogen sulphate unites with the chlorine, as the sodium takes its place. In an equation the reaction may be thus expressed: $2\,NaCl + H_2SO_4 = Na_2SO_4 + 2\,HCl$.] On a gigantic scale hydrogen chloride is prepared, as a waste product, in the manufacture of sodium carbonate.

[**Hydrogen chloride** HCl, is a compound of one atom of hydrogen, with one atom of chlorine.]

173. **Bromine** is a liquid at common temperatures, of a rich red-brown colour. It was discovered by Balard in sea-water, in which it occurs in very small quantities as magnesium bromide. The relative weight of bromine is three times that of water, in which liquid it is very little soluble. Vapour readily rises from bromine; its colour is deep orange-red, and its odour as injurious as, and more unpleasant than, chlorine. In ether bromine is very soluble.

Chlorine separates bromine from its **salts.** These are called **bromides.** POTASSIUM BROMIDE is much used in medicine. On the addition of Hydrogen nitrate to a bromide, Bromine is set free when heat is applied; orange-red fumes fill the vessel, and drops of bromine of a blood-red colour condense on its sides. If now a glass-rod, dipped into a stiff solution of starch, be held in the vessel (a test-tube is most suitable), a rich, orange-coloured, bromide of starch is formed.

[**Bromine** is an element greatly resembling chlorine. Its symbol is Br, and its atomic weight 80. In the form of vapour, bromine weighs eighty times as much as the same measure of hydrogen.]

174. **Iodine** is also an element, and, like chlorine and bromine, never found native. It was discovered by Courtois, in 1811, in the ash of sea-weed. Kelp is the ash of various kinds of sea-weed, and in it is the salt of iodine, SODIUM IODIDE, from which iodine is obtained.

Iodine resembles graphite (par 147) in appearance, and is a very heavy **solid,** with almost metallic lustre. Although but little soluble in water, to which it communicates the tint of brown sherry, it is very soluble in alcohol, and forms the Tincture of Iodine of the druggist. Iodine **melts** a little above the boiling-point of water, and boils at 175° C. Its vapour is of a splendid violet colour, for which reason the name iodine was given. Although, when taken internally, it is a virulent poison, as an outward application, especially in swellings of the glands, iodine is one of the most valuable of medicines.

Just as Bromine unites with starch, so does iodine; iodide of starch is, however, purple. The **salts** of iodine are called **iodides.** POTASSIUM IODIDE is as useful a medicine as potassium bromide. Chlorine displaces iodine from an iodide. When a drop of chlorine water is added to a solution of potassium iodide, potassium chloride is found in solution, and iodine is set free; the addition of starch immediately produces a rich purple tint.

[**Iodine** is represented by the initial letter I; its atomic weight is 127. So that the vapour of iodine is 127 times as heavy as the same measure full of Hydrogen. The manner of displacing Iodine, by Chlorine, from potassium iodide, may be seen by an equation. $KI + Cl = KCl + I$. 35½ parts by weight of Chlorine can displace 127 parts by weight of Iodine, or 80 parts by weight of Bromine.]

175. **Fluorine**, in its elementary state, is unknown, but there is every reason to believe that it is a gas. The **salts** of **fluorine** are called **fluorides**: fluor-spar is a FLUORIDE of CALCIUM. It is sometimes found massive, and of such beautiful colours, and so transparent, as to be employed for ornamental purposes. Yet the chief use to which it is put is in etching glass.

176. **Hydrogen fluoride** is employed in **etching.** The art was first practised at Nuremberg, and is now in general use. After careful cleaning, the glass is covered with a varnish made from wax and turpentine. The graver is then passed over the varnish, cutting through it so as to expose the glass, and sketching (as with a pencil) whatever the artist may desire. The fumes of

hydrogen fluoride, when directed against this surface, attack the glass only where it is uncovered, eating, as it were, the design out of it (par. 183).

[The manufacture of hydrogen fluoride is in principle similar to that of hydrogen chloride, but must be conducted in vessels of lead, as it would otherwise eat the glass away. It is a compound of hydrogen and fluorine, corrosive and dangerous to a great degree. When HYDROGEN SULPHATE H_2SO_4, is distilled with CALCIUM FLUORIDE CaF_2, CALCIUM SULPHATE $CaSO_4$, remains, and HYDROGEN FLUORIDE HF, distils. The fact may be expressed by the following equation: $CaF_2 + H_2SO_4 \doteq CaSO_4 + 2\,HF$. The combining weight of **Fluorine** F, is 19. HYDROGEN FLUORIDE is HF.]

[177. A careful study of these four elements will show how closely related they are to one another. They all unite with one atom of hydrogen, and can take the place the one of the other, atom for atom. Hence these elements, together with hydrogen, are called **monad** elements, from the Greek word signifying one.

CHLORINE, BROMINE, IODINE, FLUORINE, and HYDROGEN are then **monads.**]

CHAPTER IX.

THE ELEMENTS SILICON, BORON, AND ARSENICUM, AND THEIR COMPOUNDS, WITH AN EXPLANATION OF ETCHING GLASS.

178. The study of Chemistry in this little work has brought us thus far that we are able to understand better the nature of elements and of compounds. We have at least learnt, that all combinations take place according to fixed laws.

Just as certain letters are employed to spell certain words, and as a fixed number of letters constitute the alphabet, so in Chemistry do certain **letters** indicate certain **elements**, and always represent **fixed weights of those elements.**

179. According to their behaviour towards Hydrogen, we can **arrange** the **elements** in **classes.**

Those which unite with Hydrogen, atom for atom, are called **monads.** Others, which unite with two atoms of Hydrogen, are called **dyads**, from the Greek word signifying two. Again, others are called **triads**, and displace, or unite with, three atoms of hydrogen. Yet others are called **tetrads**, and for similar reasons, because they displace, or unite with, four atoms of hydrogen.

To take illustrations. **Chlorine** unites with hydrogen to form HYDROGEN CHLORIDE HCl; it is therefore **a monad. Oxygen** unites with hydrogen to form HYDROGEN OXIDE H_2O; it is therefore a **dyad. Nitrogen** with hydrogen forms AMMONIA H_3N; it is a **triad. Carbon** unites with hydrogen to form MARSH-GAS H_4C; carbon is therefore a **tetrad.**

180. If we add to the elements already described those also which are to form subjects for consideration in the present chapter, we obtain the following table :—

MONADS.	DYADS.	TRIADS.
Hydrogen, H = 1	**Oxygen, O = 16**	**Nitrogen, N = 14**
Chlorine, Cl = 35.5	**Sulphur, S = 32**	**Phosphorus, P = 31**
Bromine, Br = 80	TETRADS.	**Boron, B = 11**
Iodine, I = 127	**Carbon, C = 12**	**Arsenicum, As = 75**
Fluorine, F = 19	**Silicon, Si = 28**	

181. **Silicon.** The element **Silicon** is not found native, nor is it of any present importance. Nevertheless, in combination with oxygen, it constitutes the greater part of the earth's crust: as **silicic acid** it is indeed a well-known mineral.

In properties, silicon closely resembles carbon, and belongs to the same group of elements (par. 180). If heated strongly in oxygen, it burns with magnificent light to silicic acid, just as carbon burns to carbonic acid.

[**Silicon** is a tetrad element. Its symbol is **Si**; and its combining weight 28. With Fluorine, Silicon unites to form a gaseous compound, SILICON FLUORIDE SiF_4, which illustrates its character of a tetrad.]

182. **Silicic acid** is found in the pure state, and is met with as "Rock-crystal," in perfectly colourless and transparent, beautifully crystallized, six-sided prisms. The finest crystals are cut into ornaments, or are employed as substitutes for glass in spectacles, and other optical instruments. So used, they are termed **pebbles**, and they possess an advantage over glass in their extreme hardness, rendering them less liable to be scratched. The finest specimens of rock-crystal are found in the mountains of Switzerland, Ceylon, Madagascar, and the Brazils. A purple variety is known as "Amethyst." Brown and yellow rock-crystals, of great beauty and value as stones, are found in the mountain of Cairngorm in Scotland. The precious "Opal" is but a combination of silicic acid with water. All the varieties of beautiful stones known as **Agate, Bloodstone, Flint, Carnelian, Cat's-eye, Onyx, Chrysoprase, Jasper,** &c., are but varieties of silicic acid. Several of these stones are mentioned in the Book of the Revelation of St. John the Divine, and it is a curious fact that all the stones mentioned are minerals completely oxydized. But the commonest form of silicic acid is **sandstone.** Rocks of sandstone are found in nearly all countries, and, though they may differ in minor points, there are more points of resemblance. The various colours are due principally to iron-oxide. Some sandstones are very dense; others porous, and fitted for conveying water through the earth. Under the name of quartz, crystalline sandstones are in some places developed either into projecting veins penetrating other rocks, and forming picturesque objects jutting into air, or they occupy important positions in mountainous countries, remarkable alike for their picturesqueness, and absolute barrenness. **Sand** is nothing but broken-down sandstone.

Silicic acid, when pure, is insoluble in water, and infusible except in the oxy-hydrogen flame. Owing, therefore, to the intense heat required for its fusion, it cannot be melted in any ordinary furnace, and can therefore only be applied as a substitute for glass, when found in such masses as to allow of its being mechanically wrought into the required forms.

Although in itself practically infusible, and insoluble in water, at a high temperature it may be fused with many metallic oxides. Its salts are called **silicates**, and many of them are as common as they are valuable. **Glass** is a silicate (par. 237). Silicic acid is insoluble in all acids except hydrogen fluoride, but it is dissolved by boiling solutions of potassium and sodium hydrate.

[**Silicic acid** is a compound of **Silicon** and **Oxygen**, in the proportions of one atom of silicon to two atoms of oxygen. Its symbol is SiO_2. It behaves like an acid. Although so feeble, it is very powerful at a red-heat and at higher temperatures, and drives other acids out of their combinations. If sand is heated with sodium carbonate, we obtain SODIUM SILICATE, and carbonic acid is set free.]

183. **Silicon** has a great attraction for **Fluorine**; on this account hydrogen fluoride is used in etching glass (par. 176). **Silicon fluoride** is a gas, and so the fluorine literally flies away with the silicic acid of the glass. [For, when hydrogen fluoride is said to attack glass, it acts upon the silicic acid. The hydrogen unites with oxygen to form water, and then the silicon and fluorine immediately enter into combination. The following equation would express the reaction. $4\,HF + SiO_2 = 2\,H_2O + SiF_4$.]

184. A very beautiful **substitute** for **etching** was introduced in the London Exhibition of 1873 by Mr. Tilghman. It is called the patent **sand blast** process. The invention is based on the fact, that when glass is subjected to the impact of a blast of sand, the detrition of the surface exposed to its action will be rapidly effected.

185. Leaving silicon, we come to **Boron, an element**

only found in chemical combination with **oxygen.** It is never found native and, is of no present importance. One form of boron is nearly as hard as the diamond. It cannot be melted, and is insoluble in water. At high temperatures boron oxydizes, and burns into boracic acid.

Boracic acid is the only oxide of boron. The chief supplies are obtained from the steam-jets which escape from the earth in some parts of Tuscany. These vapours are conducted into water, which dissolves the acid; on evaporation of the water, the acid remains.

When obtained from water, the latter unites with the boracic acid to form **hydrogen borate.** It has then the appearance of pearly scales, which require 25 parts of cold water for solution. When gently heated it loses its water, and at a higher temperature melts into a clear glass. It is soluble in alcohol, and the solution burns with a green flame. **Salts** of boracic acid are called **borates**; thus we have HYDROGEN BORATE, SODIUM BORATE, &c. SODIUM BORATE is the "Borax" of commerce: it is found native in Thibet, and is also known as "Tincal." Borax is much used in the glaze of china, and in soldering metals.

[**Boron** is a triad element, and unites with three atoms respectively of the monads chlorine, fluorine, &c. Its symbol is B, and its atomic weight 11. **Boracic acid** is a compound of two atoms of boron, with three atoms of oxygen. Its symbol is B_2O_3. HYDROGEN BORATE is HBO_2,H_2O.]

186. **Arsenicum** is an element which likewise can only be obtained by the art of the chemist, from its **combination** with **oxygen,—arsenious acid.** When this is heated with charcoal, arsenicum is obtained.

The metals **Cobalt, Nickel** and **Iron** are frequently found united with **Sulphur,** as well as with **Arsenicum.** When heated in the air, **all these elements oxydize;** the metals remain as oxides, but the sulphur volatilizes as sulphurous acid, and the oxydized arsenicum condenses in the form of a white solid, well-known as ARSENIOUS ACID, Arsenicum is a steel-grey solid, which burns with bluish flame into arsenious acid, diffusing at the same time the odour of garlic.

187. The most poisonous of all gases is the compound which **arsenicum** forms with **hydrogen.** In composition it closely resembles ammonia (par. 156), and hydrogen phosphide (par. 166). [**Arsenicum** As, unites with hydrogen to form **hydrogen arsenide** AsH_3. It is a triad element like Phosphorus and Nitrogen, giving with hydrogen the analogous compounds AsH_3, PH_3 and NH_3.]

188. **Arsenious acid** is the "white arsenic" or "ratbane" of the shops. It can be bought in the form of a white powder, resembling flour, but much heavier. As it is very poisonous, it is not allowed to be sold in common, and only then in admixture with soot or with Prussian blue, so as to prevent its administration for wicked purposes. Salts of arsenious acid are called **arsenites.** COPPER ARSENITE is of a lovely green, but unsafe to employ in colouring wall-paper. [**Arsenious acid** resembles boracic acid in composition. Its symbol is As_2O_3. In cases of poisoning with arsenical preparations, it is well to give magnesia in gruel, and to produce sickness as soon as possible.]

189. **Arsenicum** and **sulphur** unite together to form a compound of a beautiful yellow colour, much used as a paint. It is called "orpiment."

190. The preceding Chapters have made us familiar with a class of elements often called **non-metallic.** From them we ought only to deduct arsenicum, which has been included for the sake of convenience.

At the present time, the division of the elements into **metals** and **non-metals** can only be allowed in the strict sense of the meaning, that the latter are not metals in the common acceptation of the word. For, although most of the elements which we have considered are not good conductors of heat and electricity, Hydrogen is a feeble conductor, and in every particular possessed of properties which cast its lot among the

191. **Hydrogen oxide** is a **neutral oxide** of the **metal hydrogen.** For the most part the **non-metallic elements** unite with **oxygen** to form **acid** compounds, or such as are more or less sour to the taste.

[The following will serve as illustrations, and may be altogether passed over by those who have hitherto omitted the bracketed portions.

Nitrogen, Phosphorus, Arsenicum, and **Chlorine,** unite each with oxygen, to form respectively two compounds. NITROUS ACID N_2O_3, and NITRIC ACID N_2O_5; PHOSPHOROUS ACID P_2O_3, and PHOSPHORIC ACID P_2O_5; ARSENIOUS ACID As_2O_3, and ARSENIC ACID As_2O_5; CHLOROUS ACID Cl_2O_3, and CHLORIC ACID Cl_2O_5.

Boron forms BORACIC ACID B_2O_3.

Antimony forms ANTIMONIC ACID Sb_2O_5.

Sulphur forms SULPHUROUS ACID SO_2, and SULPHURIC ACID SO_3.

Carbon forms CARBONIC ACID CO_2. **Silicon,** SILICIC ACID SiO_2.]

192. All these **acids** unite with **water** to form **salts** of the **metal hydrogen.** One example will suffice. When nitric acid, a solid, is placed in water, hydrogen nitrate is immediately formed. [This will be at once understood by the following equation: $N_2O_5 + H_2O = 2\,HNO_3$, or two atoms of HYDROGEN NITRATE.]

193. The elements **chlorine, bromine, iodine,** and **fluorine** unite directly with **hydrogen** to form **salts.** Thus we have HYDROGEN CHLORIDE, HYDROGEN BROMIDE, HYDROGEN IODIDE, and HYDROGEN FLUORIDE. HYDROGEN CHLORIDE (HCl par. 172) is therefore as much a salt of hydrogen, as is HYDROGEN SULPHATE.

It is therefore obvious from what has been said, that oxygen behaves towards hydrogen in the same manner as does Chlorine, with this difference, however, that, whereas hydrogen oxide is a metallic oxide, and, as it happens, is neutral to test-paper, hydrogen chloride is a salt of hydrogen, and turns blue litmus red.

194. **All the non-metallic elements** (except oxygen)

unite with hydrogen, to form **salts of hydrogen,** either directly or indirectly. **Directly** in the case of CHLORINE, BROMINE, IODINE, and FLUORINE: **indirectly,** in the **oxydized** form, in the case of NITROGEN, SULPHUR, PHOSPHORUS, CARBON, BORON, and SILICON.

195. If the salt of hydrogen be soluble in water, it generally reddens litmus paper. Other salts may be obtained by displacing the whole, or, where it is possible, a portion of the hydrogen by another metal. Thus, potassium nitrate is saltpetre; here potassium takes the place of hydrogen in hydrogen nitrate (par. 157).

196. **Salts of hydrogen** are in **common language** called **acids**; they possess for the most part corrosive properties. This property of corrosiveness, as well as of a sour taste, and of reddening litmus paper, is entirely lost in certain other salts. Potassium nitrate is quite neutral to test-paper, and so also is sodium chloride, and these two may be taken as types of the two classes of salts which the non-metallic elements form. [POTASSIUM NITRATE KNO_3; SODIUM CHLORIDE $NaCl$.]

CHAPTER X.

INTRODUCTION TO THE METALS—CONTINUATION OF TABLES OF THE ELEMENTS—GENERAL PROPERTIES—MEANING OF AN ORE—THE PRINCIPLES UPON WHICH THE GETTING OF THE METALS FROM THEIR ORES DEPENDS.

197. The division of the elements into **non-metals** and **metals** has been considered in paragraph 190. [Those **elements** which unite with Hydrogen, atom for atom, such as Chlorine, Bromine, Iodine, and Fluorine, are called **monad** or **monovalent** (one value); such as unite with **two** atoms of Hydrogen, or of Chlorine, Bromine, Iodine, and Fluorine, are called **dyad** or

divalent (two values) **elements.** Again, those which combine with **three** atoms of Hydrogen, or with three atoms of Chlorine, Bromine, Iodine, and Fluorine, are called **trivalent** or **triad elements**; whilst those which unite with **four** atoms of Hydrogen, or of Chlorine, Bromine, Iodine, or Fluorine, are called **tetrad** or **tetravalent elements.**]

[The following Table includes the Valency, Names, Symbols, and Atomic weights of the chief Elements.]

MONADS, or Monovalent Elements.

Hydrogen	**H**	**= 1**
Chlorine	**Cl**	**= 35.5**
Bromine	**Br**	**= 80**
Iodine	**I**	**= 127**
Fluorine	**F**	**= 19**
Potassium	**K**	**= 39**
Sodium	**Na**	**= 23**
Lithium	**L**	**= 7**
Silver	**Ag**	**= 108**

TRIADS, or Trivalent Elements.

Nitrogen	**N**	**= 14**
Phosphorus	**P**	**= 31**
Arsenicum	**As**	**= 75**
Antimony	**Sb**	**= 122**
Boron	**B**	**= 11**
Bismuth	**Bi**	**= 210**
Gold(aurum)	**Au**	**= 196**

DYADS, or Divalent Elements.

Oxygen	**O**	**= 16**
Sulphur	**S**	**= 32**
Strontium	**Sr**	**= 87.5**
Barium	**Ba**	**= 137**
Calcium	**Ca**	**= 40**
Lead	**Pb**	**= 207**
Magnesium	**Mg**	**= 24**
Zinc	**Zn**	**= 65**
Cadmium	**Cd**	**= 112**
Manganesium	**Mn**	**= 55**
Ferrum	**Fe**	**= 56**
Cobalt	**Co**	**= 58.5**
Nickel	**Ni**	**= 58.5**
Hydrargyrum	**Hg**	**= 200**
Copper	**Cu**	**= 63.5**

TETRADS, or Tetravalent Elements.

Carbon	**C**	**= 12**
Silicon	**Si**	**= 28**
Stannum (tin)	**Sn**	**= 118**
Platinum	**Pt**	**= 197**

198. The metals proper are then for the most part **good conductors** of **heat** and **electricity.** A good conductor of heat is also a good conductor of electricity.

199. All of them are **solid** at common temperatures, with the exception of Mercury, which is fluid above — 39° C. Their physical condition is, however, simply a question of temperature. Some of them, as Tin, Lead, Cadmium, and Zinc, melt below red heat; others, as Silver, Copper, and Gold, melt above a red heat, yet at a temperature easily attainable in a furnace; while some like Iron, Cobalt, and Nickel, require a bright white

heat before they will melt. Platinum is intractable in all ordinary furnaces.

200. Many metals may be **volatilized** by heat. Mercury, Cadmium, Zinc, Potassium, and Sodium are obtained by distillation.

201. **Metallic lustre**, though a common, is not an essential feature of the metals. It is due to the reflection of light. All the metals are obtainable without this lustre, while elements like Graphite, Iodine, Silicon, and Boron exhibit it also to perfection.

202. The metals are perfectly **opake**, except when beaten into very thin leaves. Gold-leaf transmits a green light.

203. The variations in **colour**, are not so great as might be expected from so large a number of the elements. Most of them present various shades of silvery whiteness, or the bluish colour of Zinc and Lead, the grey of Iron, the red of Copper, and the pale-yellow of Barium and Calcium, and the bright-yellow of Gold.

204. The metals are all **insoluble** in water, unless the decomposition of the latter is brought about (par. 145).

205. They differ greatly in **hardness**. Steel may be rendered so hard as to scratch glass, while Lead is so soft as to be readily cut with a knife, and Potassium and Sodium may be spread like butter. The very terms soft and hard are but relative, the condition of metals in this respect being affected not only by temperature, but by the mode of manufacture. A metal may be very hard, and yet have but little **tenacity**, by which we mean its power of resisting rupture by extension. Bismuth and Antimony are broken to pieces by a blow; Zinc can scarcely be bent without its cohesion being overcome; while Iron, Copper, Platinum, and Silver, possess a very high degree of tenacity. Iron is 26 times more tenacious than Lead. The relative tenacity of the metals is determined by testing the comparative strength of wires that have been drawn through the same draw-plate, and are consequently of precisely the

same diameter. Heat diminishes the tenacity of the metals.

206. When a metal can be extended, without rupture, by hammering, it is said to be **malleable.** Gold, Silver, Copper, Platinum, Iron, and Aluminum are the most malleable. Gold-leaf is only $\frac{1}{280000}$ of an inch in thickness!

207. All **malleable** metals are **ductile**, or capable of extension by drawing; but their ductility is not always in proportion to their malleability. A **ductile** metal is capable of being **drawn** into **wire**, but its value as wire depends upon its tenacity. Gold, Silver, Platinum, Iron, and Copper are the most ductile, and they are arranged in the order of their ductility.

208. The rarer metals are nearly always found **native**, or in the condition in which we employ them. Gold, Platinum, and Bismuth are always so found; Silver and Copper frequently, but not mainly.

209. Native metals often occur **crystallized**, the commonest forms of crystal being the cube (fig. 35), and the octohedron (fig. 36). Some metals may be obtained in crystals by melting several pounds weight in a crucible, breaking through the crust when it has formed, and pouring out the yet liquid metal.

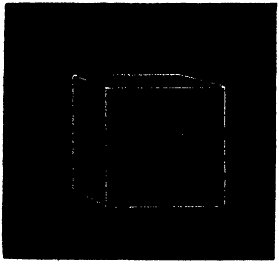

Fig. 35.

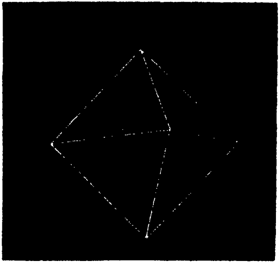

Fig. 36.

210. The variations among metals, in **density** or **specific gravity**, are remarkably great. Lithium, the lightest of all, is of sp. gr. 0·59, while Platinum is 21·53

times heavier than **water**, which is always taken as the standard of comparison of the relative weights of solids and liquids.

211. Many of the metals are capable of combination with others to form **alloys**; some of these are possessed of much beauty, others of great importance in the useful and fine arts. Copper, for instance, is not suitable for castings; but combined with zinc, it forms the alloy **brass**, and with tin, **bronze**. **Steel**, a carbide of iron, is a compound of carbon with iron. Although, in alloys, the combination is perfect, yet are the metals held together by the weakest affinities. Heat alone is sufficient to separate much of the zinc from the copper in brass.

212. A combination of **mercury** with other metals is not called an alloy, but an **amalgam.**

213. Some of the metals, as iron and platinum, possess the valuable property of **softening** before **fusion,** and in this state several pieces may be united by pressure—a mode of union known as **welding.**

214. The metals unite with the elements chlorine, bromine, iodine, and fluorine to form **salts.** In such combinations the **metal** is called the **basyl**, the other element the **radical.** If such a salt is decomposed by the galvanic current, the basyl always separates at the negative pole, at which hydrogen also separates (par. 150, fig. 30).

215. The compounds of **oxygen** with the **non-metallic** elements have **acid** properties; they redden litmus when soluble in water, and generally unite with hydrogen oxide to form a salt of hydrogen. [The **acids may** be regarded as **compound radicals; chlorine, bromine, iodine**, and **fluorine**, as **simple radicals.**]

216. Oxygen unites with the metals, and forms **metallic oxides** or **bases**, with properties the very opposite to those of acids. When soluble in water, they turn red litmus paper blue, and they unite with **acids**, or with compound radicals, to form **salts.**

217. When a basyl or metal is brought to a salt of hydrogen, the latter is often pushed out, and the new

metal takes its place. Thus HYDROGEN CHLORIDE and ZINC, yield ZINC CHLORIDE, and HYDROGEN. But, if a base, or basic oxide, be introduced into a salt of hydrogen, HYDROGEN OXIDE is formed, and a new metallic salt. Thus, HYDROGEN CHLORIDE and ZINC OXIDE would yield ZINC CHLORIDE and HYDROGEN OXIDE. [In symbols both reactions may thus be given: $2\,HCl + Zn = ZnCl_2 + H_2$. Again: $2\,HCl + ZnO = ZnCl_2 + H_2O$.]

218. Oxygen unites with the metals in different proportions, and forms different classes of basic oxides. When only **one basic oxide** is known, it is simply called by the name of the metal, as LEAD OXIDE, SILVER OXIDE, POTASSIUM OXIDE, &c., and the salts are known as those of LEAD, SILVER, and POTASSIUM. But when a metal forms **two basic oxides**, the one containing least oxygen is known by the affix **ous**, and the other containing most, by the affix **ic**. Thus we have **ferrous** and **ferric oxides**, and ferrous and ferric salts.

219. Some metals not only form basic oxides, but also **peroxides**, and even **acids**. A **peroxide** becomes a **basic oxide**, by **loss** of oxygen. [This can be accomplished either by heat alone, or by the action of a salt with a compound radical. MANGANESE PEROXIDE MnO_2 forms a good illustration. When heated to redness, it loses oxygen, and becomes a basic oxide. $3\,MnO_2 = Mn_3O_4 + O_2$ (par. 146). When manganese peroxide is heated with hydrogen chloride, the hydrogen salt of a simple radical, we obtain MANGANOUS CHLORIDE $Mn\,Cl_2$, HYDROGEN OXIDE H_2O, and CHLORINE (par. 170).]

220. **Sulphur** unites with the metals, and forms **sulphides.** Most of the oxides have corresponding sulphides, and the same distinctions are made. We have but one sulphide of lead, silver, and potassium, but there are two sulphides of iron, distinguished as FERROUS SULPHIDE, and FERRIC SULPHIDE.

221. A metallic **compound**, from which the **metal** is usually extracted, is called an **ore.** ["Hæmatite" is an ore of iron, an **oxide** Fe_2O_3, "Cinnabar," of mercury, a **sulphide** $Hg\,S$; "Malachite" of copper, a **carbonate**

222. Metallic ores do not generally compose large beds or extensive strata in the crust of our globe, but are usually found in clefts, rents, or fissures called **veins.** The process of obtaining the ores from these veins is called **mining**—a term also applied in the getting of COAL, SALT, &c. The mode of proceeding varies. The mining operations are the simplest when the vein is in strata, hills, rocks, or mountains. If the vein be exposed at the surface of the ground, the mineral is simply dug out, and the excavation thus made, serves as a passage to the interior of the mountain in following the vein. When the vein does not appear externally, or when it takes a new direction after being followed for some distance, access to it is obtained by adits or levels (horizontal galleries dug from the sides of the hill), till the vein is reached. Similar galleries are also sometimes constructed to carry off the water which drains through the higher parts of the mountain, and which would otherwise hinder the works. When the mineral lies in strata considerably below the surface of the earth, then a perpendicular pit or shaft is sunk to the required depth, and, from its bottom or sides, horizontal galleries are carried to the beds, veins, or strata. The mode of supporting the overlying mass of earth or rock, after the excavation, depends upon the nature of the mineral. Where it is valuable, the roof or cavern overhead, left by the removal of the ore, is propped up by timber or pieces of masonry; but in mines of coal or salt, the whole bed is not dug out, but masses of it are left, like columns, to support the roof of the mine.

223. Of course the **ventilation** of mines is an important consideration. The mode usually adopted is to cause a current of fresh air from the surface of the earth to descend one shaft, or one-half of a shaft, to supply the place of the impure or noxious air which is made to rise through another shaft, or through the other half of the same. The current is created, in most cases, by large fires at the bottom of the shaft,

the impure air of which being thereby heated, ascends, and fresh air must descend to take its place. The ventilation of mines depends upon principles already explained and illustrated (par. 110). The use of a second shaft is not confined to its necessity for full ventilation, but may also be of the last importance as affording to miners a second place of exit in the event of one being closed by an accident.

224. The treatment of the ores for the extraction of the metal resolves itself into two distinct operations; one **mechanical**, the other **chemical.** The mechanical process adopted depends upon the marketable value of the ore, as the greater its worth, the more labour can be profitably expended on its working.

The **chemical** management depends on the nature of the ore, which must determine whether the extraneous matters **Sulphur, Oxygen,** &c., can be removed at once, or whether their removal can only be effected after the addition of more oxygen. If the ore be a **sulphide,** as is the case with **Lead,** the first process resorted to is that of "roasting" in the reverberatory furnace, as shown in section in fig. 37. The fuel is seen to be burning on a hearth *a* separate from the bed *d* upon which the ores are laid, the flames being led over them by the bridge of the furnace. Air is admitted into the interior by means of side doors, by the opening of

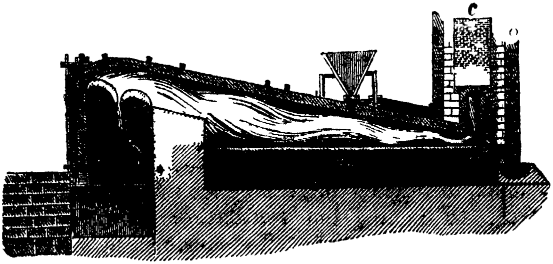

Fig. 37.

closing of which, Oxygen may be admitted, or excluded, at will. When the **doors** are wide **open, oxydation** more or less complete takes place; while with **closed doors,** the ore is **de-oxydized** or **reduced** (par. 129).

The process of **roasting** consists then in **oxydation.** The **Sulphur** of the compound unites with **Oxygen** and volatilizes as **Sulphurous acid,** whilst the **metal** also **oxydizes** and remains in the form of an **oxide.** Reduction implies, on the contrary, the bringing back of the metal, from the state of combination, to an elementary condition. **Carbon** and **Hydrogen** are the great **reducing** agents. When Hydrogen is passed over an oxide heated to redness, it reduces the oxide with formation of water, and separation of the metal. [Thus **Cupric oxide** CuO is reduced to **Cuprum** or **Copper** Cu, by **two** atoms of **Hydrogen** H_2. In symbols this action is thus expressed: $CuO+H_2=H_2O+Cu$.] The reducing power of Carbon also depends upon the facility with which it unites with oxygen; but the form in which it will pass off, whether as Carbonic oxide (par. 152) or Carbonic acid (par 151), is determined by the nature of the ore. If the metallic oxide is readily reduced, Carbonic acid will be given off, because the temperature required for its reduction is low; but if the temperature at which reduction takes place is very high, the Carbon will pass off as Carbonic oxide. [It will be remembered that Carbon unites with oxygen in two proportions, as CARBONIC OXIDE CO, and CARBONIC ACID CO_2. If STANNIC OXIDE SnO_2 were heated with Carbon, CARBONIC ACID CO_2 would escape in the form of gas, and STANNUM Sn remain. In symbols: $SnO_2+C=CO_2+Sn$. Supposing, however, that stannic oxide were not reduced except at a white heat, then carbonic oxide would be formed. And this, too, may be represented symbolically: $SnO_2+2C=2CO+Sn$.]

225. The process of **separating** a **metal** from its **ore,** is called **smelting.** In carrying out this process, it often becomes necessary to get rid of the SILICIC ACID (par. 182) contained in many ores, by means of a **flux.**

This, as the word itself indicates, is something that will liquefy. The flux employed in smelting an ordinary iron-ore consists of LIME, or CALCIUM OXIDE, which, uniting with the SILICIC ACID of the ore, forms a liquid "slag" of Calcium silicate. If the lime were not added, the iron oxide would form a slag, and would be lost as iron silicate; as soon, however, as the silicic acid is combined with the Calcium oxide, the Carbon and Hydrogen of the fuel act as reducing agents upon the iron-oxide.

226. To render this matter more intelligible, let us further illustrate it by the example of an iron-ore. The chief component of "clay-iron stone" is **ferrous carbonate.** Now, a red-heat suffices to rid the ore of its carbonic acid, and the oxygen of the air to turn ferrous into ferric oxide. [In symbols: $4FeCO_3 + O_2 = 4CO_2 + 2Fe_2O_3$.] Fuel would do the rest, and would remove the oxygen from the ferric oxide. [In symbols: $Fe_2O_3 + 3\ C = 3\ CO + Fe_2$.] But Ferrous carbonate is scarcely ever pure. The so-called Clay-ironstone, from which the greater part of British iron is manufactured, is Ferrous carbonate mixed with clay (aluminum silicate), lime-stone (calcium carbonate), and other matters. After the ore has been roasted it is ready for smelting, and this is done in the blast-furnace, fig. 38. It consists of a truncated, pyramidal mass of brickwork, about fifty feet high, and from fourteen to seventeen feet in diameter in the widest part of the cavity *a*, and with a double-coned, hollow centre. The lowest portion, or neck of the funnel, is called the crucible, and is made of the most refractory stone. On the sides are the openings for the tuyères, *b* (blast-pipes), through which hot air under pressure is introduced, these being the only openings for the supply of air. Into this furnace a mixture of equal weights of roasted ore and coal, with one-fifth of limestone (Calcium carbonate), are thrown from above. The ore is reduced through the agency of the carbon and hydrogen of the coal, and the silicic acid, contained in the clay-ironstone, unites with the

lime and alumina to form fusible silicates or "slags," which, being lighter than the metal, swim upon its surface. In quantity this slag is five times that of the iron, and is constantly run off from an opening left for the purpose. In the course of a day and night the iron is reduced to the metallic state, and is drawn off into channels of sand. In this state it is known as "pig-iron." The roasted ore yields about 35 per cent. of iron.

227. The gases which escape from the top of the furnace, *c*, consist principally of nitrogen (from the air), carbonic oxide, hydrogen, light carbonetted hydrogen, and carbonic acid.

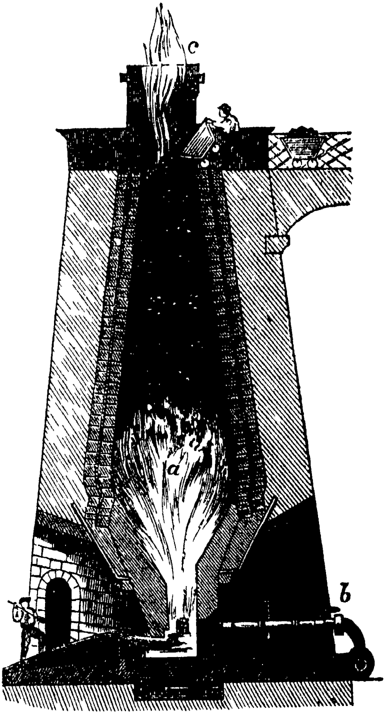

Fig 38.

CHAPTER XI.

ON CERTAIN CARBONATES AND SILICATES, TOGETHER WITH A SHORT DESCRIPTION OF GLASS, CHINA, AND EARTHENWARE.

228. As the extent of this work is much too limited to allow of any treatment of the metals, some attention may be given to a few metallic salts. The **salts** of **carbonic** and **silicic acid** will form the subject of the present chapter. [CARBONIC ACID CO_2, and SILICIC ACID SiO_2, unite with WATER H_2O, to form HYDROGEN CARBONATE H_2CO_3, and HYDROGEN SILICATE H_2SiO_3.]

229. **Potassium carbonate** is the pearl-ash of the shops. It is a white, granular salt, so very soluble in water that it attracts moisture from the air, and flows into a liquid (deliquesces). Red litmus paper is turned blue, by its solution in water. On burning wood, an ash remains consisting principally of this salt; when dissolved in water, and evaporated in iron pots, it constitutes "potash." [The metal **Potassium** or **Kalium** is made by heating the carbonate with charcoal.]

230. **Sodium carbonate** is well-known as washing-soda. The so-called **bi-carbonate of soda** is a white powder resembling pounded sugar; it is not nearly so alkaline as the carbonate, because it contains less soda. It is sometimes used to neutralize the acidity of beer, to soften water, and for making effervescing draughts. [SODIUM CARBONATE Na_2CO_3, is also employed in making **Sodium** or **Natrium**: $Na_2CO_3 + 2C = 3CO + Na_2$.]

231. **Ammonium sesqui-carbonate** is popularly known as "smelling-salts." Its stimulating properties are owing to the evolution of ammonia, or hartshorn.

232. **Calcium carbonate** is one of the most abundant of rocks and minerals. In a pure form it is met with crystallized, as "Iceland Spar" and "Calcspar." LIMESTONE, CHALK and MARBLE are varieties of Calcium carbonate, and so also is "Coral." Shells also consist

nearly entirely of calcium carbonate. In water it is nearly insoluble, as a gallon will only take up two grains. When, however, water contains carbonic acid, as nearly all waters do, then it is much more soluble and gives rise to calcareous waters. [So also the precipitate of calcium carbonate is re-dissolved, when carbonic acid gas is continued to be passed into lime-water. On boiling such a solution, which is called CALCIUM BI-CARBONATE $CaCO_3,CO_2$, Carbonic acid escapes, and CALCIUM CARBONATE is deposited.] This solution of **Calcium bi-carbonate** gives to spring and sea-waters one of their great characteristics—**hardness.** Carbonic acid thus breaks down some of the hardest limestone-rocks by a purely chemical process, and becomes the occasion of one of the commonest natural phenomena of limestone districts, viz., the enormous natural caverns peculiar to them. The roofs of these are often found clothed with pendent masses of calcium carbonate which hang like icicles, called by the name of "Stalactites," while their floor is covered with a thick layer of the same nature, formed by the droppings from the stalactites, and known as "Stalagmites." Their formation is due to the facility with which the lime-laden water, when exposed to the air, parts with the excess of carbonic acid; then, as it is no longer able to hold in solution all the calcium carbonate, a portion is deposited.

Such springs are frequent with us in England, where they are known as "petrifying wells." "Boiler-crusts" arise from such waters, and so also does the "fur" in kettles.

In Italy, a building-stone in common use, known as "Travertine," and composed altogether of calcium carbonate, is deposited from volcanic waters. An example occurs in a lake existing in the Campagna of Rome; the water is so saturated with calcium bi-carbonate as to assume a bluish, milky, aspect. The ancient Romans erected their baths here. "Reeds, lichens, confervae, and a vast mass of aquatic vegetation," says Sir H.

Davy, "here find a rich repast, and grow in the utmost luxuriance, forming a number of floating islands on its surface." Fig 39.

When a water contains calcium bi-carbonate in solution, it can be **softened by boiling**; such water is called **temporarily hard** The crust of calcium carbonate is a very bad conductor of heat, and very much impedes the boiling of water in kettles and boilers.

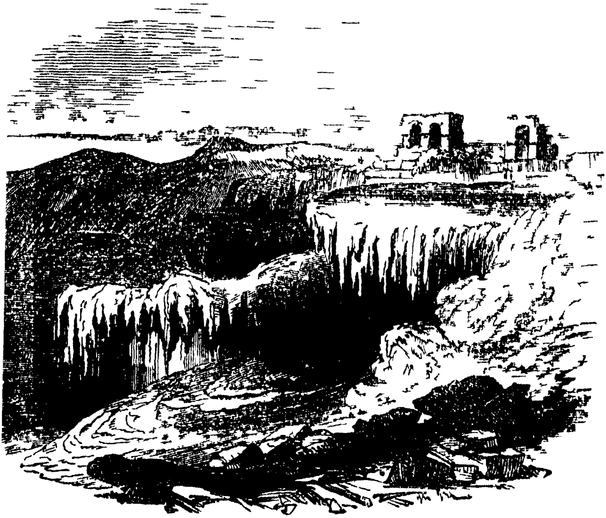

Fig 39

233. There are many other carbonates. As a rule, when they are heated to redness, they give off Carbonic acid, and the **oxide** remains. We have a good illustration of this in the making of "quick lime" (Calcium oxide): Calcium carbonate becomes **Calcium oxide** when thus heated.

234. The **silicates** are of great importance. Granite is a mixture of various silicates with silicic acid. Both "Mica" and "Felspar" are silicates.

285. **Calcium silicate** is contained in window-glass, and is formed by melting calcium carbonate together with silicic acid. [$CaO,2SiO_2$, is the formula.]

286. "Clay" is a silicate, and indeed an **aluminum silicate.** When pure, it is perfectly white, and is employed in making china. Heated to redness, clay shrinks but does not melt, and hence it is employed in making fire-bricks. The common clays are more or less coloured, owing to the presence of iron as ferric oxide; they are perfectly insoluble in water, and very retentive of moisture, insomuch that a stiff clay is never deprived of all its moisture by the hottest sunshine.

287. **Glass** is a **mixture** of various **silicates:** the most important of which are the SILICATES of POTASSIUM, SODIUM, CALCIUM, and LEAD. In its most familiar form, glass is a transparent, brittle substance, very ductile just before the point of fusion, and therefore very easily wrought into any desired form. The extent of its fusibility depends altogether upon the nature of the silicates employed. In the manufacture of the superior qualities of glass, everything depends upon the judicious selection of materials.

288. POTASSIUM CARBONATE must always be employed when perfectly colourless glass is wanted. SODA, although it furnishes a glass of greater lustre than Potash, communicates to it a greenish tinge.

289. CALCIUM OXIDE may be employed as quick-lime, or in the form of calcium carbonate. It is chiefly used in the manufacture of flint-glass.

240. Next to these, LEAD-OXIDE ranks in importance as an ingredient in glass-making, its presence being the distinguishing characteristic of flint-glass. It is used both in the form of lead-oxide, and red-lead, a higher oxide of lead. The great use of lead-oxide lies in its power of forming very fusible silicates, possessing a high metallic lustre; but, unfortunately, **lead silicate** is very soft and easily scratched.

241. Among the **essentials** to glass-making, must be mentioned **broken glass** and **decolourizing agents.**

BROKEN GLASS, or "cullet," as it is called, being more fusible than any of the raw materials, is employed for the purpose of facilitating their fusion. The object of the decolourizing agents is to remove accidental impurities, such as carbonaceous matters from the fuel, and the Ferrous-ferric oxide which colours all common glass. The most useful material for this purpose is MANGANESE PEROXIDE, which has been already several times alluded to as a source of Oxygen (par. 146). The ease with which this substance gives off oxygen, and changes the Ferrous, into Ferric oxide, renders it a most fitting agent in the removal of the chief discolouring matter in glass. Another agent, RED-LEAD, is preferred in glass-making to lead-oxide, on account of its finer state of division, and because its excess of oxygen is given off at a red-heat, thus oxydizing the charcoal, and any other organic impurities, that may have become mixed with the ingredients.

242. The **mixture** of the materials for **glass-making** is technically called "Frit." Their fusion is effected in large conical crucibles, Fig. 40, made of the most infusible fire-clay, and which have been previously heated nearly to whiteness.

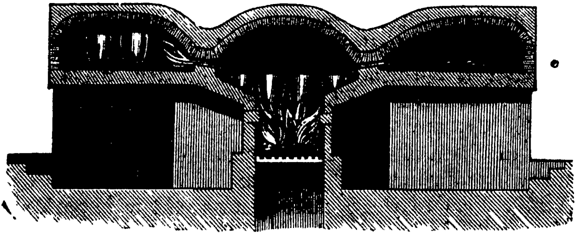

Fig. 40.

243. The **chemical action** is simple, and one explanation will suffice for all kinds of material. If we suppose, for example, the **silicic acid** to be mixed with **potassium carbonate**, Carbonic acid is expelled, and

potassium silicate produced. As long as the evolution of Carbonic acid lasts, the whole mass is kept in agitation by the escape of the gas, and thus the mixture of the materials is promoted.

244. The glass, however, does not for a long time become transparent, owing partly to the unwillingness of the last gas-bubbles to make their escape, and partly to the excess of lime, and of other earthy impurities that will not fuse. For the purpose of allowing these to settle, and the gas to escape more freely, the temperature of the furnace is raised so as to render the glass as fluid as possible, the process occupying, in all, about 48 hours. This being accomplished, the temperature is gradually lowered by regulating the draught, so as to allow the glass to assume the pasty consistence, in which it may be readily shaped at pleasure into the required form.

245. **Plate-glass** and **common window-glass** consist chiefly of **sodium** and **calcium silicates**, and are therefore made from the raw materials, sand, soda-ash, calcium carbonate (chalk), and cullet. Great care is required that the Calcium carbonate be not in excess, as the glass would in that case appear milky on cooling. [Crown-glass may be said to be a mixture of POTASSIUM SILICATE, with CALCIUM SILICATE. Its chemical formula would be thus expressed : $K_2O,2SiO_2,CaO,2SiO_2$.]

246. In Continental manufactories, and in many of our English ones, glass is first blown into the form of a spheroid, which, when its ends are cut off, leaves a cylinder which is divided by means of shears, or by a straight line traced by a drop of water. It is then taken to the furnace to be spread out, or flattened by means of an iron rule into a sheet (fig. 41).

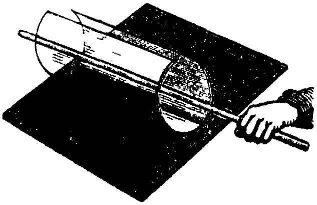

Fig. 41.

247. **Sheet-glass** is far less brilliant and more wavy than crown-glass, and it is much improved by grinding and polishing.

248. The process of **annealing** is of great importance, all glass being inclined to brittleness, and liable to fly. The perfection of the process depends entirely on the temperature of the furnace in which the operation is conducted; if too high, the glass would partially melt and lose its shape; if too low, the plates would be badly annealed, and would be likely to fly when taken out.

249. In **Bohemian glass**, POTASSIUM and CALCIUM SILICATES are the chief ingredients. The ornamental varieties contain in addition ALUMINUM SILICATE.

250. **Flint-glass** is chiefly employed for the numerous articles of domestic use for which England is so greatly celebrated. It is so called, because the silicic acid with which it is made, was formerly exclusively obtained from **flints**, calcined, and ground. From other glass it is distinguished, by containing lead oxide, instead of calcium oxide. It is more transparent, lustrous, fusible, more free from colour, and heavier than other descriptions of glass. Its one defect is its comparative softness, rendering it so liable to be scratched.

The composition of flint-glass may be judged from its formula, $K_2O,3SiO_2,PbO,3SiO_2$.]

251. The **cutting** of glass is accomplished by a grinding process; the **roughing** by the use of sand.

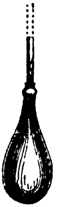

Fig. 42.

252. **Bottles** are made of the cheapest materials. The sand always contains ferric oxide (iron-oxide), which not only gives colour, but greater fusibility. A heated pipe having been dipped into the melted glass, and a certain quantity thus collected, is withdrawn by a continuous rotary motion; when the glass has become sufficiently consistent not to bend on itself, the blower blows through the pipe, fig. 42, and gives the glass somewhat of the

form of an egg. After having introduced it into a mould of a proper form, as soon as the bottle is formed, the blower withdraws it from the mould, and by a see-saw motion raises it on high, as in fig. 43, and indents the bottom of the bottle. Then, taking a drop of water, he applies it to the neck of the bottle, which is immediately carried to a small cavity in the side of the furnace, and separated from the pipe by a dexterous jerk. The bottle being thus prepared, the blower turns it, and fashioning the pipe to its base, extracts from the pot, with another pipe, a small quantity of melted glass, which he can draw out like thread. The end of this he brings to the neck of the bottle, and, by a rotary motion, surrounds the mouth with a small glass cord; he then introduces the neck into the working-hole, and finishes the mouth with pincers. The bottle being completed, an assistant takes it from the hand of the master-workman, carries it to the annealing-furnace and detaches the pipe by a dexterous blow (Regnault).

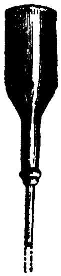

Fig. 43.

253. **Etching,** or engraving on glass, is effected by hydrogen fluoride (par. 176).

254. The art of **staining,** must have been nearly of the same age as the discovery of glass; or rather it may be asserted, that it was at all times easier to obtain a coloured, than a colourless glass. The imitation of precious stones, so commonly found with Egyptian mummies, shows that the knowledge of the various colours obtainable in glass, must have been even then very complete. The so-called painted glass, used in our ancient churches, is only superficially coloured; the method of colouring the glass throughout, now generally adopted, was acquired in the fifteenth century.

255. Glass **windows** were first introduced into England in the seventh century. The Venerable Bede mentions the glazing of the church and monastery of Wearmouth, A.D. 674. Their use, however, was for

centuries confined to ecclesiastical buildings, the windows of dwelling-houses, even among the wealthy, being filled with oiled paper, or wooden lattice-work, until about the thirteenth century. The finest sort of window-glass is said to have been made in 1557 at Crutched Friars; and, shortly afterwards, the first flint-glass was made at the Savoy House, in the Strand. The first plate-glass for looking-glasses, coach-windows, and the like purposes, manufactured in England, was made in Lambeth in 1670, by workmen brought from Venice by the second Duke of Buckingham. From that time English glass began to rival the best manufacture of France and Venice, and now supplies the largest and finest descriptions to a considerable portion of the globe.

256. **Aluminum silicate** or **clay**, is, in its way, as useful as the various silicates which compose glass. **Aluminum oxide**, is better known as alumina. It is found nearly pure as CORUNDUM; "emery" is an impure corundum. The RUBY and the SAPPHIRE also consist of alumina, tinged with colouring matters.

257. The metal **Aluminum** was discovered by Woehler, and derives its name from alum, which is a salt of aluminum and potassium. It is never found native. The chief uses of aluminum are: for the purposes of ornament, the manufacture of small weights, and the production of aluminum-bronze—an alloy of copper and aluminum.

258. The plastic qualities of clay (aluminum silicate), and its power of hardening under the influence of heat, must have suggested at a very early period in the history of man its application in the making of utensils for the many requirements of daily life; while scarcely any art has made greater advances from its rude commencement, and probably none has been more indebted for its progress to the aid of science.

259. The **bricks** of which our houses are built, the **slates** and **tiles** with which they are roofed, the **china** and **earthenware** which we use, are all of them but

varieties of **clays**, so abundantly distributed over the earth.

260. When slowly dried, clay shrinks considerably, and soon exhibits its unfitness, by itself, to form good utensils. It does not fuse even under exposure to the greatest heat of an air-furnace, but shrinks and splits into hard pieces. When burnt it is still perfectly white, and adheres tenaciously to the tongue. It is greatly absorbent of water, acting like capillary tubes (par. 140) and allowing the water to flow through.

261. The only clay suitable for the manufacture of porcelain, is that called **kaolin** or **china-clay.** But even this is not able to perform all the service required of it, without the assistance of some substance to obviate the two defects just mentioned as common to all clays; viz., its porosity, and its troublesome property of shrinking as it dries. These faults are entirely remedied by **admixture** of the clay with **silicic acid**, the same substance which was found to be so essential in the manufacture of glass.

262. **Clay, calcined flints,** and some **cement** capable of partial fusion, are all the materials required for the various kinds of porcelain.

263. After the flints have been calcined, they are transferred to the grinding vats in which, by mechanical force, they are ground to powder. The china-clay and flints having both been stirred with water to a similar cream-like consistency, the two fluids are thoroughly mixed in the blending reservoirs. From these the mixture is passed through fine sieves, and finally into a receiver of open kilns where the excess of water is evaporated by heat. When tolerably firm, the mixture is cut into blocks, and reduced by pressure into the perfectly plastic state, in which it is required for use by the potter.

264. **Felspar**, if not already present in the clay (as it frequently is) in sufficient quantities, is added to the flint previous to its mixture.

265. Before the paste is worked up, it is again

mixed by hand, and squeezed into balls, which are violently thrown on to the table at which the potter is at work.

The process of **throwing** and **turning** on the potter's wheel, must be witnessed to be understood. In executing his work, the potter is guided not only by patterns, but also by various measures, or moulds, for shaping the article in hand. If the work be on a large scale, the clay is added in successive batches as required.

266. In **moulding**, the paste is applied to the mould, the form of which it is intended to assume. The mould is always made of a porous material, capable of absorbing the moisture from the clay, generally of "Plaster of Paris." When the pattern is very complex, the mould is made in several pieces. For round objects it is made in two parts, fitting each other exactly; the article being moulded in separate halves, which are united while the paste is yet moist. When the paste has been sufficiently dried by absorption of its moisture by the mould, the latter is removed by separating its two parts, leaving the work complete.

267. The moulded articles have next to be thoroughly **dried.** This is done by baking them in the so-called biscuit ovens. Porcelain which has passed through this process is called **biscuit ware.**

268. The very porous ware requires now the protection of the **glaze,** and is generally accomplished by **dipping** : it consists of finely-pounded felspar and quartz, held in suspension by vinegar and water, and is applied by very rapid immersion and removal of the ware. A skilled workman is said to be able to dip seven hundred dozen plates in a day.

269. The materials used for **colouring porcelain** are much the same as for glass. Most of them are **silicates**, which, after fusion, are reduced to an impalpable powder, and ground into paint with oil of lavender. They are applied with the brush before the glazing, and the porcelain is heated sufficiently to fuse them.

Black is produced by an OXIDE OF URANIUM; **brown** by FERRIC and MANGANOUS OXIDES. The **pink** colour used on china is prepared by heating a mixture of POTASSIUM DICHROMATE, CHALK and STANNIC OXIDE. CHROMIC OXIDE gives the **green**, COBALT OXIDE, the **blue** colours most in vogue. Common **gilding** is effected by mixing pulverulent gold, a little borax, and bismuth oxide, with essence of lavender, the mixture being applied with a brush. After burning, the gold appears dead, and is polished, first with an agate, and afterwards with a blood-stone burnisher.

270. **Stoneware** is a coarser description of porcelain, containing both FERRIC OXIDE and LIME, to the presence of which it owes its colour and fusibility. This ware is seldom glazed by dipping. When the pottery has attained a high temperature, a handful of dry sodium chloride (common salt) is thrown into the furnace; it is volatilized and decomposed, by the joint action of the silicic acid of the ware, and the vapour of water. Hydrogen chloride, and sodium oxide are produced; the former passes off in vapour, and the latter is deposited as a **glaze** of SODIUM SILICATE upon the surface of the ware.

271. The **colour** applied to Staffordshire ware is generally **blue**, on account of the cheapness and easy application of COBALT OXIDE. The patterns are printed off upon paper, which is applied, while wet, to the ware before it is glazed. When the ink is dry, the paper is washed off, and the glazing completed in the manner already described.

CHAPTER XII.

OTHER METALLIC SALTS.

272. The **carbonates** and **silicates** mentioned in the former chapter will serve as illustrations of their charac-

ter: they are very numerous, and their importance can be estimated by the youngest reader.

273. The **Chlorides** are all soluble in water, except "calomel" or **mercurous chloride**, and **silver chloride.** **Potassium chloride** crystallizes in cubes. It is largely contained in kelp, and is consequently a constituent of sea-water. **Sodium chloride** [$NaCl$] is our "common salt." Water dissolves rather more than one-third of its weight, and deposits a portion, from a hot solution, in cubes. The sea-water about our coasts contains 2·7 per cent., which is equal to rather more than 4 ozs. per gallon. The crystals decrepitate, or break up with noise, when strongly heated, owing to the moisture shut up in them. The chief deposit of salt, with us in England, is at Northwich, in Cheshire. But there is a deposit of rock-salt in Poland, at Wielitzka, which is no less than five hundred miles long, 20 miles wide, and 1,200 feet thick. Sodium chloride is of much use in the arts. [Firstly, as a source of **Hydrogen chloride** (par. 171), and of **Sodium sulphate.** Thus, when heated with hydrogen sulphate we obtain: $2NaCl + H_2SO_4 = Na_2SO_4 + 2HCl$. Secondly, as a source of **Sodium carbonate.**]

Calcium chloride is a white, deliquescent substance, much used in drying gases. It is always produced in making Carbonic acid from Calcium carbonate.

274. Calcium chloride must not be mistaken for **Chloride of lime**, which emits **Chlorine** on exposure to air, and is highly valued as a bleaching and disinfecting agent. It is prepared on a large scale by exposing Calcium hydrate to the action of Chlorine gas: the latter simply drives out water from the hydrate, and takes its place. [Thus: CALCIUM HYDRATE CaH_2O_2 + CHLORINE, two atoms, Cl_2 = WATER H_2O + CHLORIDE OF LIME or CALCIUM OXYCHLORIDE $CaOCl_2$.] The only part of chloride of lime, of any value, is that which is soluble in water; the rest consists mainly of slaked lime. For household use, one part may be dissolved in 10 parts of water, filtered through a coarse cloth, and kept in a

stoppered bottle ready for use. A piece of a worn towel, or other useless cloth soaked in the solution, and suspended in a room, will act as a disinfectant as long as chlorine can be recognized by the smell.

275. Several of the **chlorides** are employed in making the respective **metals.** If MAGNESIUM CHLORIDE, or ALUMINUM CHLORIDE, be heated strongly with the metal SODIUM, SODIUM CHLORIDE is formed, and the metals **Magnesium**, or **Aluminum**, are obtained.

276. The **Bromides** and **Iodides** resemble the chlorides: some of them are of great importance in medicine as well as in the arts. **Potassium bromide** is used in the preparation of the element **Bromine** (par. 173). **Sodium iodide** is contained in the ash of sea-weeds, and is resorted to in the manufacture of **Iodine** (par. 174). The salt of iodine most valued in medicine is, however, **Potassium iodide.**

277. [When Sodium iodide is heated with Manganese peroxide and hydrogen sulphate, we obtain Sodium sulphate, Manganous sulphate, Water, and Iodine. In an equation, the reaction would be thus expressed: $2NaI + MnO_2 + 2H_2SO_4 = Na_2SO_4 + MnSO_4 + 2H_2O + I_2$.]

278. There is but one **Fluoride** of importance found native. **Calcium fluoride** CaF_2, is known as the mineral "fluor-spar," so much used in etching glass (par. **176.**) It will be remembered that when Calcium fluoride is distilled with hydrogen sulphate, Hydrogen fluoride passes over. [This will be understood by the following symbols: $CaF_2 + H_2SO_4 = CaSO_4 + 2HF$.]

279. **Hydrogen sulphate** has been already mentioned; it is the most energetic of all the salts of Hydrogen, and is therefore used for setting free other hydrogen salts. **Potassium sulphate** results from the manufacture of Hydrogen nitrate, and **Sodium sulphate** from the preparation of Hydrogen chloride. Only a few others can be described. **Calcium sulphate** is found native as "Selenite," "Gypsum," and "Alabaster." It occurs also crystallized, and requires 400 parts of water for solution. This salt is contained in

many waters and confers the property of "**permanent hardness**," as distinctive from the "temporary hardness" of calcareous waters containing calcium bi-carbonate; such a water, on evaporation, deposits a crust difficult to remove, because so little soluble. When heated to 260°C, Calcium sulphate loses its water of crystallization, and acquires the property of "setting" when mixed with water. It becomes "Plaster of Paris." [The difference will be seen by comparing the formulæ: GYPSUM is $CaSO_4,2H_2O$; PLASTER OF PARIS $CaSO_4$.]

280. **Magnesium sulphate** is the well-known "Epsom salts." It dissolves in less than three times its own weight of water, and the solution possesses the bitter taste which belongs to the soluble salts of Magnesium. [Magnesium sulphate, like Calcium sulphate, contains water of crystallization, all of which is lost much below red-heat. The crystals of Epsom salts contain 7 molecules (par. 306) of water, and are represented by the formula $MgSO_4,7H_2O$.] **Ferrous sulphate** is known in commerce as "green vitriol" and "copperas." The crystals are of a pale sea-green colour. On a small scale the salt can be prepared by dissolving Iron in diluted Hydrogen sulphate; Hydrogen is driven out, and Iron takes its place. The solution in water must then be evaporated, and crystals will be obtained. [When Iron (Ferrum), and Hydrogen sulphate, are brought together, the following equation will explain the reaction: $Fe + H_2SO_4 = FeSO_4 + H_2$. The Dyad Ferrum, separates 2 atoms of the Monad Hydrogen. Ferrous sulphate crystallizes with 7 molecules of water of crystallization.] **Zinc sulphate** is commonly called "white vitriol." It resembles Magnesium and Ferrous sulphates, in that it contains the same amount of water of crystallization. The **salt** is always **produced** in the **making** of **Hydrogen** (par. 145). [$Zn + H_2SO_4 = ZnSO_4 + H_2$. Sixty-five parts by weight of the metal zinc will yield two parts by weight of Hydrogen.] By evaporating the liquid which remains in the Wolffe's bottle, Zinc Sulphate may be obtained in crystals

shaped like needles. **Copper sulphate** is called "blue vitriol," and is the only common salt of Copper. The crystals are of a rich blue colour; when they are heated, they lose their water of crystallization, and become white. [**Copper sulphate** $CuSO_4,5H_2O$ contains 5 molecules of water.] In conclusion it may be mentioned that all **Sulphates** are **soluble** in **water**, except those of the metals **Barium**, **Strontium**, and **Lead**.

281. **Potassium nitrate** is "saltpetre." It crystallizes from water in six-sided prisms, and melts when heated; at a higher temperature it loses oxygen. Its chief use is in making **hydrogen nitrate** (par. 157), and **gunpowder.** The latter is a mixture of saltpetre, charcoal, and sulphur; when detonated, the explosive force of gunpowder is due to the large quantities of heated Carbonic acid and Nitrogen gases, which are set free. **Sodium nitrate** is found native near Iquique in Peru. It is known in commerce as "cubic nitre," and is much employed as a manure, and likewise in making **hydrogen nitrate** [$2NaNO_3 + H_2SO_4 = Na_2SO_4 + 2HNO_3$]. **Barium nitrate** gives the colour to "Green-fire," and **Strontium nitrate** to "Red-fire." All nitrates are soluble in water.

282. The **Chlorates** resemble the nitrates both in composition, and in properties. **Potassium chlorate** is much used in making **Oxygen** (par. 146). The salt crystallizes in scales. As soon as it is melted, the temperature rises, and then Oxygen is given off: the chlorate, by loss of Oxygen, being changed into chloride. [POTASSIUM CHLORATE $KClO_3$, by loss of its Oxygen, becomes POTASSIUM CHLORIDE KCl. 122½ parts by weight of potassium chlorate, would yield 48 parts by weight of Oxygen. This will be understood by the following statement. A compound is built up by, and is the sum of, its components. Now the smallest particle of Potassium chlorate is found to consist of one atom of Potassium, one atom of Chlorine, and three atoms of Oxygen. By referring to par. 197, we find the atomic weights of these three elements to be :—

Potassium or **Kalium**	39
Chlorine	35.5
Oxygen	16

But three atoms of Oxygen are contained in one atom of the salt Potassium chlorate. We must therefore multiply the atomic weight of Oxygen = 16, by 3 = 48. The reckoning now stands thus :—

Kalium	39
Chlorine	35.5
Oxygen	48
	122.5

Although the space in this elementary work is very limited, another fact will now be easily comprehended by the intelligent reader. A **measure**, called a **Litre** by the French, and equal to $1\frac{3}{4}$ pint, is generally employed in speaking of the volume of Gases. One **Gramme** by weight (about $15\frac{2}{5}$ grains) of Hydrogen, measures $11\frac{1}{5}$ Litres. Inasmuch as Oxygen is 16 times heavier than Hydrogen, 16 Grammes of Oxygen will be found to fill the same measure as 1 Gramme of Hydrogen. So that, as 3 × 16 Grammes of Oxygen are contained in $122\frac{1}{2}$ Grammes of Potassium chlorate, we can obtain 3 × $11\frac{1}{5}$ Litre measures, or $33\frac{3}{5}$ Litres of Oxygen, from $122\frac{1}{2}$ Grammes.

283. The **preparation** of any **Element** is not a matter of guess-work, but one of the completest confidence. If we want a certain **weight** of Oxygen, we take a given **weight** of the salt. A chemist works with the full knowledge that God works uniformly, according to what we are pleased to call **Laws of Nature.** As Dr. Chalmers has said, the constancy of Nature is a testimony to the faithfulness of God. And it has been by study of Nature, that man has begun to appreciate the method observable on every side.

284. The **Phosphates** also form a numerous class of **salts. Calcium ortho-phosphate** (par. 167) is the chief ingredient of a burnt bone, or of " bone-earth." When

a bone is burnt, an **ash** remains, which consists mainly of this salt. "Super-phosphate of lime" is made from bone-earth: it is preferable, as a manure, because it is soluble in water. From the super-phosphate, **Phosphorus** is made. [In principle, the **manufacture of Phosphorus** depends upon the action of Charcoal, at a white heat, on METAPHOSPHORIC ACID HPO_3; CARBONIC OXIDE CO, HYDROGEN H, and PHOSPHORUS P, result. Phosphorus is collected under water. $4HPO_3 + 12C = 2H_2 + 12CO + P_4$. Two volumes of Phosphorus, in vapour, contain four atoms, par. 169 and 307.]

CHAPTER XIII.

ILLUSTRATIONS OF METALLIC OXIDES AND HYDRATES, WITH SHORT DESCRIPTION OF THE SALTS CALLED SOAPS.

285. Many of the **Elements** are known to **oxydize** readily; so readily indeed, that it would be impossible to preserve them, as such, in the air. We are obliged to keep **Potassium** and **Sodium** in benzol, or some other liquid consisting only of Carbon and Hydrogen, for in the air they oxydize with remarkable rapidity. If the air be dry, the two metals are changed respectively into **Potassium oxide** [K_2O], and **Sodium oxide** [Na_2O].

286. **Some metals** take fire when heated in air, and **burn** with wonderful brilliancy **into** metallic **Oxides.** Magnesium and Zinc form excellent illustrations; they become changed into **Magnesium oxide** [MgO], and **Zinc oxide** [ZnO].

287. Nearly all metallic **Oxides** are insoluble in water, but they have all a great tendency to unite with water, and to form **Hydrates.** Thus, common "Rust" is a **Ferric hydrate**; "Caustic potash" is **Potassium hydrate,** and "Slaked Lime" is **Calcium hydrate.**

288. **Hydrates,** as well as **Oxides,** are, for the most

part, insoluble in water. When soluble, they turn red litmus paper blue.

289. LITMUS is much used as a test. The blue colouring matter of litmus is furnished by a Lichen, the **Roccella tinctoria,** which grows upon rocks on the sea-coasts of Corsica, Sardinia, &c. The blue colour is reddened by acids, and restored by alkalies.

290. **Potassium oxide** is a white solid, which dissolves with great heat in water, as POTASSIUM HYDRATE, or CAUSTIC POTASH. This hydrate is prepared on a large scale by dissolving Potassium carbonate in water, and adding slaked lime, or Calcium hydrate; Calcium carbonate separates, and, on cooling, the potassium hydrate may be poured off as a clear liquid. The liquid is boiled down in an iron or silver basin, and the solid residue is melted if required.

Potassium hydrate is a greyish-white solid, which deliquesces, or flows into a liquid, when exposed to damp air. On account of its caustic properties it is used in surgery, and is generally sold in sticks, which have been cast in moulds. Its solution in water is intensely **alkaline** (par. 156), and blues red litmus.

The affinity of potassium hydrate for carbonic acid is very great, and, as a test, it is indispensable to the chemist. It is also used in making soft soap.

[**Potassium hydrate** KHO, may be regarded as **water** HHO, in which one atom of Potassium, or Kalium, has displaced one atom of Hydrogen. 39 parts by weight of Potassium, displace 1 part by weight of Hydrogen. Both Potassium and Hydrogen are Monads, par. 197.]

291. **Sodium oxide** is yellowish-white, with a greedy affinity for water, with which it forms SODIUM HYDRATE, or CAUSTIC SODA. It is much used in making hard soap. On a small scale it can be made from Sodium carbonate, by means of slaked lime, in exactly the same manner as potassium hydrate: it has similar properties.

[$Na_2CO_3 + CaH_2O_2 = CaCO_3 + 2NaHO$. **Sodium hydrate** is then $NaHO$.]

292. **Calcium oxide** is the well-known "quick-lime." It forms a white, infusible mass, but little soluble in water. When 56 parts by weight are mixed with 18 parts of water, they enter into combination with great heat, and form **Calcium hydrate**, the well-known "slaked lime." Calcium oxide is made upon a large scale by heating lime-stone to redness, and it is extensively employed in making Mortars and Cements. The **solution** of Calcium hydrate is well known to chemists as **Lime-water**, and is **used** as a **test** for Carbonic acid (par. 151).

[**Calcium oxide** CaO, unites with **water** H_2O, to form **Calcium hydrate** CaO,H_2O. When Carbonic acid is passed into Calcium hydrate, it unites with Calcium oxide to form Calcium carbonate $CaCO_3$, and pushes out the water. Calcium hydrate is used in making both Potassium and Sodium hydrates.]

293. **Magnesium oxide** is the "Magnesia" of the chemist. Like Lime, it is a white, infusible solid, but almost insoluble in water. Nevertheless it turns red litmus blue. Like Calcium oxide it also forms a **hydrate.**

294. No substances are possessed of such powerful **cleansing properties** as **Potassium** and **Sodium hydrates.** Both of these are soluble in less than half their weight of water, and both have the power of dissolving the skin with very great rapidity. They possess further the remarkable property, of being able to enter readily into combination with every variety of fatty matter, to form compounds which are soluble in water. Every requisite in a cleansing agent appears united in Potash and Soda, save one; their destructive action upon the skin, would render their employment, by themselves, quite out of the question. The discovery, therefore, that they were capable of uniting with fatty matters to form compounds possessed of nearly all their cleansing powers, with little or none of their caustic properties, was a great step in advance towards their practical application.

295. Such **animal** and **vegetable fats** as are fit for employment in **soap-making** are so similar in character, that they may be considered together. When melted, or if naturally liquid, they all produce a greasy stain upon paper or linen: in the case of a **volatile oil,** this stain **disappears** on the **application** of even a moderate **heat,** but is permanent in the case of a **fixed oil** or **fat.** All fats are insoluble in water; how much, therefore, must their composition become changed, when they unite with Potash and Soda to form **Soaps** readily **soluble** in **water.**

296. The **fixed fats** are really **Salts** of **Glycerin.** STEARIN and PALMITIN are in reality STEARATES and PALMITATES of GLYCERIN. They contain, respectively, Stearic and Palmitic acids, in combination with Glycerin (par. 142).

Glycerin is the sweet principle of fixed oils and fats, and derives its name from the Greek word signifying sweet. It is a viscid, colourless liquid, soluble in water, and detracts from the hardness of stearin and palmitin: it is wanted neither for candles (p. 60), nor for soap. In PRICE's patent candles, the palmitic acid is separated from the glycerin, with which it is united, by means of high-pressure steam. When a mixture of palmitin and water is forced under strong pressure through tubes at a low red heat, so as to raise the temperature to about 260° C, the palmitin is decomposed into glycerin and palmitic acid. The glycerin dissolves in the water, and the palmitic acid is found completely separated.

297. In the **manufacture** of **Soap** the same object (the separation of the glycerin) is attained by bringing the fixed fats and oils together with Potassium and Sodium hydrate. **Hard soaps** are made with **Sodium hydrate; soft,** with **Potassium hydrate.** Hard soaps may, however, be made with potassium hydrate, if a hard fat is employed, but generally a fish-oil, or a vegetable drying-oil, is used with it.

298. A **good Soap** should be a definite **chemical**

compound. The presence of any excess of water, or of any material foreign to its purpose as a cleansing agent, detracts from its value. Potash-soaps are as a rule more soluble than soda-soaps. Both are said to be soluble in distilled water, but in reality this solution consists in a ready separation of the more soluble alkali, whose presence renders soap of such value in the removal of fatty matters.

299. Used in a **water** containing certain **salts** of Calcium and Magnesium, **Soap** is **decomposed**; the water becomes full of flakes, and the cleansing properties of the soap do not come into play, until the whole of the Calcium and Magnesium have been precipitated.

The action is quite simple. CALCIUM and MAGNESIUM SULPHATES are decomposed; SODIUM SULPHATE is found in solution, while the fatty acid in the soap, unites with the Calcium and Magnesium, to form **Soaps** which are **insoluble** in water. Hence the **waste** of soap arising from the use of **hard water**, and the importance of soft water for domestic purposes.

300. It is also clear that, when employed in **cleansing** our linen, the Potash and Soda in the Soap are expended in the **formation**, with the Grease contained in the linen, **of a soap soluble in the water.**

CHAPTER XIV.

CONCLUDING REMARKS.

301. It will have been understood from what has been said, even by those who have altogether left out the bracketed portions, that **few** of the **Elements** are to be met with in the **free state**, or **native**. Most of them are found in combination with **oxygen**, or in an **oxydized form.**

302. The two **elements** best **suited** for the **removal** of **Oxygen** from **metallic Oxides**, are **Hydrogen** and

Carbon. Hydrogen unites with Oxygen to form HYDROGEN OXIDE (Water), while Carbon forms CARBONIC OXIDE or CARBONIC ACID. Generally, a somewhat high temperature is required for the removal of Oxygen, but, in most cases, the application of a fuel like coal, or wood, is able to bring about the reduction. Depending upon this fact, we obtain **iron** from any of its **oxydized** compounds (par. 226).

303. The **elements unite** with one another in **fixed** and **never-varying proportions.** Such are the compounds with which we have become familiar. Carbonic acid is a compound, of 12 parts by weight of Carbon, with 32 parts by weight of Oxygen. The symbol which represents Carbonic acid as CO_2, shows it to consist of one atom of Carbon with two atoms of Oxygen.

304. It is quite a feature of chemical **combination,** that substances **acquire new properties** on combining with each other, and that their **weight** remains **unchanged.** **Carbon,** as **charcoal,** and **Oxygen,** which so brilliantly supports the combustion of the heated charcoal, differ exceedingly from the **result—Carbonic acid,**—which extinguishes combustion. And yet, we always find, that 12 parts by weight of pure Carbon can be burnt by 32 parts by weight of Oxygen, into 44 parts $(32 + 12 = 44)$ by weight of Carbonic acid.

305. The **atomic weight** (par. 197) of each **element** has been **found** by **comparing** the **different proportions** in which different elements **combine.** The **atomic weight** of each element is the **proportion** of the **weight** of its **atom** to that of **hydrogen.** **All substances** are then **built** up of **atoms.**

306. The **smallest quantity** of an element, capable of existing in the free state, is called its **molecule.** As a rule, the **molecule** is made up of **two atoms,** and, as gas or vapour, occupies the space of two volumes. Oxygen may be taken as an illustration. The **atom** of Oxygen, or the **smallest quantity** of **Oxygen** in a **state** of **combination,** weighs 16 times as much as the atom of

Hydrogen, and is expressed by the symbol O. But the **molecule** of Oxygen, O_2, represents **two atoms.** And so also do the molecules of Hydrogen, Nitrogen, Chlorine, Bromine, Fluorine, &c.

307. The **vapour** of **Phosphorus** is an **exception** to this rule. In one volume of Phosphorus vapour, we find two atoms; in two volumes (the molecule), we find 4 atoms. This has been already stated in **par.** 284.

308. When **compounds** are met with in the form of **gas** or **vapour**, it is found, that the smallest quantity that can exist in the separate state, also occupies the same space as two atoms of Hydrogen. In other words, the molecule of the compound, takes up the same space, as the molecule of Hydrogen, Oxygen, or other element. The **symbol** for Carbonic acid CO_2, represents, therefore, **not only** the molecule, but also **two measures** or volumes.

309. It may further interest the reader to know, how the **Chemist arrives** at such a **symbol** as CO_2, for **Carbonic acid.** Now, 100 parts of Carbonic acid consist of—

Carbon	**27·27**
Oxygen	**72·73**
	100·00

If we divide 27·27 by the weight of the atom of Carbon = 12, we get 2·273, or say $2\frac{1}{4}$, and if we divide 72·73 by the weight of the atom of Oxygen = 16, we have 4·545, or nearly $4\frac{1}{2}$. The relation between the numbers of the atoms of Carbon, and those of Oxygen, is obviously in the proportion of one of Carbon to two of Oxygen. CO_2, therefore expresses accurately the composition of Carbonic acid. The gas contains its own volume of Oxygen. When the plant, in presence of light, decomposes Carbonic acid, and retains the Carbon, it gives off exactly the same volume or measure of Oxygen gas (par. 47).

310. If we compare together **equal measures** of Oxygen and of Hydrogen, we find not only their **relative**

weights or specific gravities, but also their **atomic weights.** But if we wish to **compare** the weights of **equal volumes** of Carbonic acid and of Hydrogen, we must **divide** the atomic weight of the former by **two.** And this, because the molecule of Carbonic acid occupies the same space as the molecule of Hydrogen.

The molecule of Carbonic acid CO_2, fills the same measure as the molecule of Hydrogen H_2.

As the molecule of Carbonic acid weighs 44, and that of Hydrogen 2, it follows that equal measures of the two gases must weigh, respectively, 22 and 1. In other words, the same measure of Carbonic acid weighs 22 times as much, as the same measure of Hydrogen. As 11⅕ litres (par. 282) of Hydrogen weigh 1 gramme, and the same measures full of Oxygen weigh 16 grammes, so also do 11⅕ litres of Carbonic acid weigh 22 grammes.

311. We **know nothing** at all about the **constitution** of the **elementary atoms**; we only know that we **cannot**, at present, **break them up** into simpler forms. Much as is already known in Chemistry, very much more remains to be learnt; and it is only by experiment that the number of facts can be increased, and thus additions made to our knowledge.

THE END.

INDEX.

Acids, 95.
Acid, arsenious, 89.
—— boracic, 88.
—— carbonic, 67, 103, 125.
—— muriatic, 81.
—— nitric, 71.
—— palmitic, 60.
—— phosphoric, 76.
—— silicic, 86.
—— sulphuric, 74.
—— sulphurous, 74.
Air, 29.
Alkaline, 70.
Alloys, 95.
Aluminum, 110, 115.
Amalgams, 95.
Ammonia, 27, 70.
Arnott's ventilator, 46.
Arsenicum, 88.
Atoms, 66, 124, 125, 126.
Atomic weights, 78, 124.
Attraction, capillary, 59.

Barometer, 32.
Black lead, 65.
Blast-furnace, 101.
Boiling, 10.
Bone-earth, 118.
Borax, 88.
Bromine, 82.

Calcareous waters, 103.
Calcium fluoride, 115.
Calomel, 80.
Candles, 58.
Capillary attraction, 59.
Carbon, 65.
Carbonates, 69, 102.
Carbonic acid, 67, 103, 1[illegible]6.
———— oxide, 48.
———— sulphide, 75.
Chalk, 102.
Chemistry, 5.
Chapters, Contents of, iii.
Charcoal, 25.
China, 111.
Chlorate of Potassium, 117.
Chlorine, 79.
Chloride of Lime, 114.
Clay, 110.
Clouds, 36.
Coal, 42.
—— gas, 47.
Coal-mines, 56.
Coke, 46.
Combustion, 40.
Conduction, 9.
Convection, 10.
Copper sulphate, 117.
Cube, 94.

Davy-lamp, 56.
Dew, 19.
—— point, 20.
Diamond, 65.
Diffusion, Law of, 31.
Distillation, 12.
Dyads, 85.

Earthenware, 110.
Elements, 92.
Emery, 110.
Etching, 87.

Ferrous sulphate, 116.
Fire-damp, 55.
Flame, 49.
Flints, 108.
Furnace, reverberatory, 98.

Gas, 47.
Glass, 105.
Glaze, 112.
Glycerin, 122.
Graphite, 65.
Gypsum, 115.

Hydrates, 119.

Hydrogen, 61.
——— chloride, 81.
——— fluoride, 83.
——— nitrate, 71, 117.
——— oxide, 7, 61.
——— phosphate, 77.
——— phosphide, 76.
——— sulphide, 73.
——— sulphate, 84.
Hygrometer, 20.

Ice, 8.
Iodine, 82.
Iron, 100, 124.

Kalium, 102, 120.

Lamp-black, 65.
Lead, White, 69.
Lime, 121.
—— phosphate, 119.
Litmus, 120.
Lucifers, 77.

Magnesia, 121.
Magnesium sulphate, 116.
Manganese peroxide, 96.
Metals, 91.
Mining, 97.
Molecules, 124, 125, 126.
Monads, 85.

Natrium, 119.
Natural, 5.
Nitrates, 71, 117.
Nitrogen, 17, 18.

Octohedron, 94.
Ores, 97.
Oxides, 95, 119.
Oxygen, 17, 63.
Ozone, 29.

Phosphorus, 75, 119, 125.
Physical, 5.
Plumbago, 65.
Potassium, 119.
——— hydrate, 119, 120.
Pyrites, 73.

Quartz, 86.

Radiators, 20.
Reduction, 53.
Roasting ores, 100.
Rock-crystal, 86.

Safety-lamp, 56.
Salts, 95.
Salt, Beds of, 114.
Saltpetre, 117.
Sapphire, 110.
Silicic acid, 86.
Silicates, 104, 110.
Silicon, 85.
Simple bodies, 6.
Slags, 101.
Snow, 21.
Soap, 120, 122.
Sodium, 102, 114.
——— hydrate, 120.
Stalactites, 103.
Steel, 95.
Stoneware, 113.
Sulphates, 75, 115, 116.
Sulphur, 72.
Sulphides, 73.
Sulphites, 74.

Tables, 72, 79, 92.
Tetrads, 85.
Thermometers, 11.
Triads, 85.

Vapour, 19.
Ventilation, 45, 97.
Vitriol, Oil of, 74.

Water, 7, 16.
——— hard, 104.
Wells, Artesian, 15.
Wicks, 59.
Wood, 43.

Zinc, 63.
—— sulphate, 116.

LONDON:
PRINTED BY JAS. TRUSCOTT AND SON,

PUBLICATIONS

OF THE

Society for Promoting Christian Knowledge.

Most of these Works may be had in ornamental bindings, with gilt edges, at a small extra charge.

	Price	
	s.	d.
Adventures of Marshall Vavasour, Midshipman. With three full-page illustrations on toned paper. Crown 8vo .... *cloth boards*	1	6
Africa Unveiled. By the Rev. H. ROWLEY. With Map, and eight full-page illustrations on toned paper. Crown 8vo *cloth boards*	5	0
Australia's Heroes; Being a slight Sketch of the most prominent amongst the band of gallant men who devoted their lives and energies to the cause of Science, and the development of the fifth Continent. By C. H. EDEN, Esq., Author of the "Fortunes of the Fletchers," "Home of the Wolverene and Beaver," &c. With Map. Crown 8vo...*cloth boards*	5	0
Brave Dame Mary; or, The Siege of Corfe Castle. With three full-page illustrations on toned paper. Crown 8vo .... *cloth boards*	2	0
Castle Cornet; or, The Island's Troubles in the Troublous Times. A Story of the Channel Islands. By LOUISA HAWTREY. With four full-page illustrations on toned paper. Crown 8vo .... *cloth boards*	2	0
Charlie Tyrrell, and other Tales illustrative of the Lord's Prayer. By C. E. BOWEN, Author of "New Stories on Old Subjects." Three full-page illustrations on toned paper. Crown 8vo .... *cloth boards*	1	6
China, the Land and the People of. A short Account of the Geography, History, Religion, Social Life, Arts, Industries, and Government of China and its People. By J. THOMSON, Esq., F.R.G.S., Author of "Illustrations of China and its People," &c. With Map, and twelve full-page illustrations on toned paper. Crown 8vo .... *cloth boards*	5	0
Effie and her Ayah; or, The Faithful Monkey and his little White Mistress. On toned paper, with four full-page illustrations. Royal 16mo .... *cloth boards*	1	6

[1. 11. 76.] [Fcap. 8vo.

Silent Jim: a Cornish Story.
By JAMES F. COBB, Esq., Author of "A Tale of Two Brothers," &c. With four full-page illustrations on toned paper. Crown 8vo .... *cloth boards* 3

Stories of Success, as illustrated by the Lives of Humble Men who have made themselves Great.
By J. F. COBB, Esq., Author of "Silent Jim." With four illustrations on toned paper. Crown 8vo ... *cloth boards* 3

The Children of Seeligsberg: a Tale of the Lake of Lucerne.
By the Author of "Madeleine's Forgiveness," "The Cathedral Organist." 18mo... .... *cloth boards* 1

Village Beech-Tree, The; or, Work and Trust.
With four full-page illustrations on toned paper. Crown 8vo .... *cloth boards* 2

Wreath of Mallow, The, and other Stories more or less true.
By Mrs. JEROME MERCIER. With three page woodcuts, on toned paper. Crown 8vo .... *cloth boards* 2

New Series of 3s. 6d. Books.

Post 8vo, with Coloured Frontispiece and Title, Four Full-pag Woodcuts, and numerous small Engravings.

A Cruise on the Bosphorus, and in the Marmora and Æge Seas.
By the Rev. G. FYLER TOWNSEND, M.A., Author of "T Sea Kings," "Siege of Colchester," &c.

Away on the Moorland: a Highland Tale.
By A. C. CHAMBERS, Author of "Robin the Bold," &c.

Julian's Dream. A Story of A.D. 362.
By the Rev. GERALD S. DAVIES, Author of "Gaudentius," &

Rosamond Ferrars.
By M. BRAMSTON, Author of "The Panelled House," &c.

The Settlers: a Tale of Virginia.
By W. H. G. KINGSTON, Esq., Author of "The Two Sh mates," "Michael Penguyne," &c.

Two Campaigns: a Tale of Old Alsace.
By A. H. ENGELBACH, Esq., Author of "Lionel s Revenge," &

Depositories:

77, GREAT QUEEN STREET, LINCOLN'S-INN FIELDS;
4, ROYAL EXCHANGE; 48, PICCADILLY;
AND BY ALL BOOKSELLERS.